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JOINT USE OF PRODUCTION- AND CONSUMPTION-BASED ENERGY ACCOUNTINGS FOR COUNTRY ENERGY ASSESSMENT

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«It is all very well and
good to pursue these high-minded scientific theories, but research
grants are expensive and you must justify your existence by providing
not only knowledge, but concrete and profitable applications as well»

Sidney K. Meier

"O di immortales! non intellegunt homines, quam magnum vectigal sit parsimonia."

Marcus Tullius Cicero
Paradoxa Stoicorum; Paradox VI, 49

A mi familia.

Acknowledgments

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Gracias a mis amigos por estar siempre conmigo, ya sea para impulsarme o para pasar buenos momentos.

Abstract

The global concerns about contamination, energy security and sustainable development, and the incontestable relationship between energy and economy, have put the focus of researchers and policy-makers in energy efficiency. Nowadays, most governments and organizations are trying to enhance investments and actions to improve national energy efficiency. And one crucial aspect to be discussed are the methods to provide policy and decision-makers with a set of useful information to be fully aware about where and how apply efforts, and which will be the consequences of such efforts. The aim of this work is to propose a methodology capable to provide information regarding energy hotspots in nations and economic sectors and their links and relationships, in terms of energy, with other countries and sectors.

To fulfill that target, a methodology is proposed based on different phases: First, the identification of possible action areas and stakeholders involved on the process. Stakeholder identification is a key point for clarify responsibilities and enhance cooperation and coordination. On the other hand, identification of action areas helps to clarify the kind of actions to be taken in order to achieve goals successfully. For do this, a benchmarking matrix is developed, facing stakeholders with specific action areas, and relating them through energy recommendations extracted from specialized literature. Second, developing a method of energy assessment combining the goodness of production-based accounting (PBA) and consumption-based accounting (CBA). Being focused on fossil fuel resources, this method presents several advantages, since allows to analyze the whole energy metabolism, from the resource extraction to the final consumption of goods and services, thanks to the joint use of both accounting paradigms. This allows researchers to build what the author calls Energy Maps, representing the economies in terms of energy in several levels (global, national and sectoral). Such kind of maps are capable to expose energy hotspots in terms of energy flows between countries and/or economic sectors, and also the relationships between them. With this information, policies and interventions can be centered on the proper places for maximize the potential of improvement and saving. Based on this, an algorithm for energy assessment has been developed, being its main output a preliminary draft of an energy strategy based on the benchmarking process and the assessment results. As an application example of the methodology proposed, a study case is applied to Africa. In that context, stakeholders and action areas are identified and related by research in literature. The assessment proposed is applied to African regions highlighting the main energy hotspots and providing a preliminary sketch of an energy strategy involving and enhancing the cooperation of several countries.

The main achievements of this work are the combination of PBA and CBA for create the representation of whole energy metabolism of analyzed economies. To distinguish and define three kinds of energy dependency, clearly related with three trade-steps in the energy chain, and also with three kind of energy improvements. Another important statement is the differentiation of a Supply and Demand sides, both in the PBA and CBA methods. Finally, using the statements made, and a benchmarking process, an algorithm has been designed, capable to give valuable information and advertisement to policy-makers when designing energy strategies towards an efficient use of energy resources and sustainable development; always looking for a reduction in the consumption of fossil fuels

Key Words: Production based accountings, consumption based accountings, energy map, energy metabolism, energy policy-making.

Resumen

Las preocupaciones globales sobre la contaminación, la seguridad energética y el desarrollo sostenible, y la relación incontestable entre la energía y la economía, han puesto el foco de los investigadores y los responsables políticos en la eficiencia energética. Hoy en día, la mayoría de los gobiernos y organizaciones están tratando de potenciar las inversiones y las acciones para mejorar la eficiencia energética a nivel nacional. Y un aspecto crucial a ser discutido son los métodos para proporcionar a los responsables políticos y tomadores de decisiones una serie de información útil para que sean plenamente conscientes de dónde y cómo aplicar esfuerzos y cuáles serán las consecuencias de tales esfuerzos. El objetivo de este trabajo es proponer una metodología capaz de proporcionar información sobre hotspots de energía en naciones y sectores económicos y sus vínculos y relaciones, en términos de energía, con otros países y sectores.

Para cumplir con ese objetivo, se propone una metodología basada en diferentes fases: Primero, la identificación de posibles áreas de acción y los actores involucrados en el proceso. La identificación de las partes interesadas es un punto clave para aclarar responsabilidades y mejorar la cooperación y la coordinación entre ellas. Por otro lado, la identificación de áreas de acción ayuda a aclarar el tipo de acciones que se deben emprender para lograr los objetivos con éxito. Para ello, se desarrolla una matriz de benchmarking que enfrenta a las partes interesadas con áreas de acción específicas y las relaciona a través de recomendaciones de energía extraídas de literatura especializada. En segundo lugar, el desarrollo de un método de evaluación energética que combine las ventajas de la contabilidad basada en la producción (PBA) y la contabilidad basada en el consumo (CBA). Centrado en los combustibles fósiles, este método presenta varias ventajas, ya que permite analizar todo el metabolismo energético, desde la extracción de recursos hasta el consumo final de bienes y servicios, gracias al uso conjunto de ambos paradigmas de conteo energético. Esto permite a los investigadores construir lo que el autor llama Mapas de Energía, representando las economías en términos de energía en varios niveles (global, nacional y sectorial). Este tipo de mapas son capaces de exponer hotspots de energía en términos de flujos de energía entre países y / o sectores económicos, y también las relaciones entre ellos. Con esta información, las políticas y las intervenciones pueden centrarse en los lugares adecuados para maximizar el potencial de mejora y ahorro. En base a esto, se ha desarrollado un algoritmo de evaluación energética, siendo su principal resultado un anteproyecto de estrategia energética basado en el proceso de benchmarking y los resultados de la evaluación. Como ejemplo de aplicación de la metodología propuesta, se aplica un caso de estudio a África. En ese contexto, las partes interesadas y las áreas de acción son identificadas y relacionadas por investigación en literatura. La evaluación propuesta se aplica a las regiones africanas destacando los principales hotspots energéticos y proporcionando un bosquejo preliminar de una estrategia energética que implica y refuerza la cooperación de varios países.

Los principales logros de este trabajo son la combinación de PBA y CBA para crear la representación del metabolismo energético de las economías analizadas. Distinguir y definir tres tipos de dependencia energética, claramente relacionados con tres etapas de comercio en la cadena energética, y también con tres tipos de mejoras energéticas. Otra declaración importante es la diferenciación de los lados de la Oferta y la Demanda, tanto en los métodos de la PBA como de la CBA. Por último, se ha diseñado un algoritmo capaz de dar valiosa información y publicidad a los responsables políticos al diseñar estrategias energéticas para un uso eficiente de los recursos energéticos y el desarrollo sostenible. Siempre buscando una reducción en el consumo de combustibles fósiles

Palabras clave: Contabilidad basada en la producción, contabilidad basada en el consumo, mapa energético, metabolismo energético, formulación de políticas energéticas.

Extended Summary

Understanding, quantifying and representing the global primary energy supplied and demanded by sectors of national economies is nowadays crucial for policy-makers in order to define effective policies and to properly set energy efficiency and energy saving targets. Energy accountings based on the traditional Production-based paradigm (PBA) allows to understand how primary energy is directly extracted, traded, transformed and used within each economy. On the other hand, Consumption-based energy accountings (CBA) allows to understand the ultimate economic purposes of such energy flows. Therefore, the information provided by the joint application of these approaches may bring useful and complementary insight on the global economy, allowing to identify hotspots for potential interventions from both the supply and demand side. This work analyzes and represents the energy metabolism of economies based on a Multi-Regional Input-Output framework, taking into account non-renewable fossil energy, namely raw coal, crude oil and natural gas. The research is based on IEA energy data and on the EORA26 database, considering year 2013. Starting from the results of a conventional Production-based analysis, a method is here proposed to decompose the energy embodied in final goods and services: from the supply side, it allows to quantify the energy directly and indirectly invoked by the economic sectors of the nations to produce the final demand. Conversely, from the demand side, traditional Leontief impact model allows to account for the energy embodied in products consumed as final demand by each economy. Finally, results of the analysis are reconciled in order to provide what theauthor cals Energy Maps, which reflect both PBA and CBA energy information.

Introduction.

As stated by IEA and other organizations, energy efficiency is becoming a crucial issue in energy policy-making both at national and international level, it will be a key point pursuing the global climate change goals set at COP21 at Paris. Arguments in favor and against policies enhancing energy efficiency have been made by researchers mainly based on the so called rebound effect, because of which an improvement on energy efficiency will have as a consequence a decrease on unitary energy price, what causes an increase in energy consumption due to the price elasticity characteristic of energy services. However, most surveys agree that, while rebound effect is a fact, it is not hard enough to provoke negative effects as a consequence of efficiency improvements. Consequently, by promoting responsible use of resources it is possible to detach the trends of energy use and economic growth and even the increasing trend of CO2 emissions. So, two different benefits could be extracted, an economic (energy security, job creation, productivity increase, etc.) and an environmental one (shift from fossil fuels to RETs, decrease of harmful emissions, moderate industry footprint, etc.) while achieving the main goals toward sustainable development.

Improving energy efficiency in national economies.

Most of literature regarding energy efficiency is related to study, quantify, and analyze the so called rebound effect, in other words, discussing if energy efficiency improvements are good or finally bad due to second order effects. Despite of that it is possible to find some interesting definitions for energy efficiency in science publications. Oikonomou et al. stablish an interesting differentiation between energy efficiency, which they associate with technological improvements and progress; and energy savings, meaning a responsible use by end-consumers, i.e. related with behavior of final users and reductions of final demand. Arbex and Perobelli make a new differentiation relating efficiency to the origin of the energy resources (i.e. renewable, non-renewable, fossil fuels, etc.). Thus, from now, it is proper to speak about energy performance improvements toward sustainable development, and classify them as efficiency improvements (technology), energy savings (demand), and resource use shift (production). So, three different ways to act in energy systems in order to achieve sustainable development goals.

Regarding the methods to quantify or analyze it, Tanaka et al. Propose several indicators based on production accountings (i.e. taking into account only direct energy requirements) of energy and thermodynamics. For avoid the fact of taking into account just the direct energy requirements it is necessary introduce Input-Output (IO) models, based on Leontief theory, as is done by Guevara et al. which use IO analysis for extract several indicators regarding energy performance. However, the model stated by Guevara does not allow to make distinction between demand and supply sides, making impossible to have an indication about the proper policies to apply to enhance the energy system. Nevertheless, all literature seems to be focus in discussing whether if energy efficiency is beneficial or not, and measure, quantify or define indicators of energy performance in national economies. There are no surveys about how to identify and locate hotspots in which apply efforts in order to achieve energy improvements and provide information to policy-makers toward the issue of efficient use of energy resources; neither an approach that analyzes and highlights relationships and synergies between countries and economic sectors in terms of embodied energy. In this work, a novel approach in an IO framework is proposed, in a combination with production based accountings (PBA) with the aim to provide valuable information and insight to policy-makers about where and how apply efforts (and so, budget) towards energy performance improvement (technical efficiency, energy savings, and kind of resource used) for achieve the highest potential of enhancement and the highest benefits in terms of energy.

Production- and Consumption-based energy accountings.

A critical issue when trying to quantify or measure energy efficiency is the energy accounting. In 1997 the UNFCCC in Kyoto defined the accounting method for GHG emissions as production-based. From then, that method has been followed by most organizations and researchers, such as IEA. Basically, the model consists in quantify energy by means of resource production place (Primary production), then reflecting the imports/exports of raw resources, stablishing the TPES (Total Primary Energy Supply), which after discount losses on conversion processes and industry own use, turns into the TFC (Total Final Consumption), what is the energy consumed by the main sectors that forms the national economy. PBA method presents some major advantages, such as reflecting the origin of production of energy resources, the international trade of raw energy resources, and the losses in energy conversion processes. However, it has also important drawbacks. When looking for reduce emissions, policies based on PBA could lead to carbon leakage, giving place to the displacement of pollutant activities from developed to developing countries, and when accounting for energy, some activities with a small direct energy requirements could have very large “hidden” or indirect energy requirements, such as construction industry. This fact could dupe policy-makers when designing energy strategies. Finally, energy embodied in international trades are not reflected neither, so it is impossible to analyze the energy links between nations beyond the raw resource trading.

On the other hand, exist the consumption based accounting (CBA) methods. These methods are based on Leontief’s productive model. By means of an Input-Output framework, direct and indirect energy requirements are properly allocated to the economic sectors or countries. CBA is becoming increasingly relevant in policy and decision making since modern economies are complex and they are globally linked, making energy systems and energy policies a global issue. The main advantage of this approach is the trueness of energy requirements (and responsibility for energy consumption) since both direct and indirect requirements are considered. Energy embodied in international trades is also exposed, and consequently policies based on a CBA won’t be affected by the carbon leakage phenomenon. This accounting method helps in clarifying responsibilities in energy consumption both among countries and economic sectors. The main drawback related to CBA is about the data. For develop this accounting method, IO tables are required, and results are achieved after a more or less complex calculation. Two problems arise from that, first the lack on data or the poor accuracy on data in IO tables, and secondly the result uncertainty related to the calculation process and the data reliability. The second major issue of CBA is related to the practical implementation of energy policies, which should be defined at global level through complex international policy agreements. In fact, the CBA allocation of responsibilities in terms of emissions (commonly traduced on export taxes), usually brings distributional concerns and political resistance. Authors like Jakon, Steckel and Edenhofer have stated that in order to solve these issues, trade measures should be complemented with some form of free allocation of emission permits as well as sectoral approaches, which would need international cooperation and agreements.

Another important point is to set the kind of resources to be accounted and the space boundary for the accounting. Since energy policy is a global concern, the space boundary should be set at global level, however logic claims to set space sub-boundaries at the national territorial frontiers of each country. For sake of simplicity, multi-national region boundaries could be set too. The answer to the question of what resources should be accounted for, depends on the kind of survey or the kind of policies to be applied. Since in this work we are looking for efficiency improvements towards sustainable development; economic profits; and environmental concerns, the resources accounted for are strictly limited to fossil fuels (i.e. coal, natural gas and oil). Furthermore, fossil fuels state for more than 80% of global energy production and total primary energy supply (TPES). In addition, fossil fuels are the main responsible of GHG human related emissions. In this way, it is possible to stablish three different energy indicators regarding for energy hotspots: Primary Production (which states for resources production or extraction), TPES (which states for the energy “burnt”), and embodied energy consumption (which states for the energy actually consumed). In the figure below the differences between each energy indicator in several world regions could be seen. From these differences and from the definition of each indicator some interesting conclusions could be extracted. For example, which regions are the main fossil fuel exporters/importers, in which regions is energy mainly burnt and where it is consumed directly and indirectly.

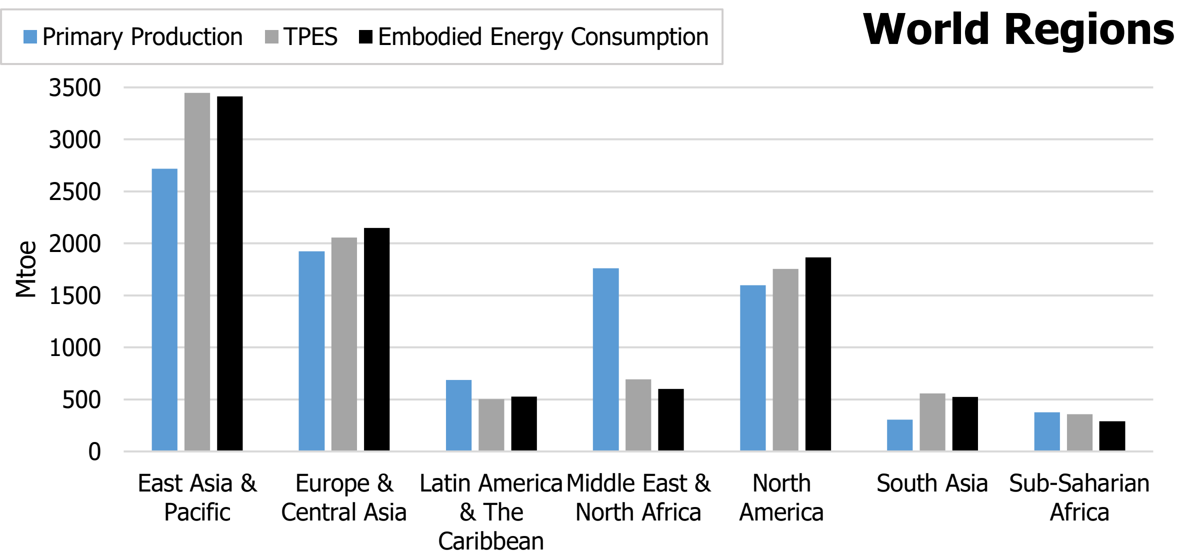

Figure 1. Different Energy Accounting Methods.

Aim of the work.

Consequently the following needs are identified and tried to be satisfied along this work

1. Models to search for hotspots in energy systems, looking for information about where apply efforts towards energy improvements.
2. Models splitting the system in demand and supply side, to be able to quantify the links and relationships between economic sector and countries in order to find synergies when designing energy policies.
3. The joint use of Production and Consumption based paradigms in a single accounting model,to be able to exploit the main advantages of both approaches.

Then, the main objectives of this research can be listed as follows:

- To propose a method based on production- and consumption-based models to better understand the energy metabolism of national economies at different scales (national and sectoral level) and being capable of:

- Split CBA in a supply and demand side and find energy relationships between sectors and countries.

- Identify main stakeholders and action areas, and relate it with the three definitions of energy performance enhancement (energy efficiency, energy savings, resource use).

To show an example of the application and usefulness of such kind of methodology, it will be applied to a case study. Regarding the problem of carbon leakages, and growing importance of developing countries in the global energy perspective, an additional objective can be set:

- To apply such method to the African continent, identifying energy hotspots for energy efficiency improvements, and relate them with specific interventions.

This research contributes to the literature in several ways: first, a method for using PBA and CBA together is presented, proposing an idea for a joint use of both accounting methods that allowsresearchers to represent and analyze the whole energy metabolism of a certain economy. Secondly, by using non-conventional Multi-Regional Input-Output (MRIO) approaches, demand and supply side are distinguished in CBA, highlighting the different kind of links between economic sectors and/or countries. This makes easier the identification of hotspots and synergies when making policies toward energy system improvement. Finally, the what the author defines as Energy Maps are proposed, in order to provide a graphical way to present the previous results in an energy report or in policy-makers advisement. The energy maps admit several levels of aggregation (from global to a national economic sector) and depending on it, different useful information for policy-making is provided.

Methods and models

Benchmarking Matrix

A very important issue when designing energy policies or energy strategies is to be able to identify the involved stakeholders and achieve a proper coordination and cooperation between them. This is de aim of the Benchmarking Matrix. This conceptual matrix, built and thought by requirement of the African-EU Energy Partnership AEEP () Energy Efficiency Workstream and used in this thesis, relates different stakeholders with action areas through energy interventions extracted from literature. Stakeholders forms the rows of the matrix, and the action areas the columns. So, each pair stakeholder-action area contains some energy recommendations related to them. This process should be done taking into account the context on the economies analyzed and the targets of the survey (the same for stakeholder identification).

In this work, the stakeholders identified can be listed as follows.

- Public Sector:
  - Local
  - Regional
  - National
  - International
- Private Sector:
  - Small and Medium Sized Enterprises (SMSEs)
  - Large Enterprises
- Civil Society:
  - Non-Profit Organizations
  - Profit Organizations
- Academia
- Research:
  - Public
  - Private
- Individuals

And the action areas:

- Energy chain:
  - Energy resource
  - Energy conversion
  - Transmission & Distribution
  - End-use devices & Building environment
- Cross cutting issues
  - Policies
  - Capacity building
  - Behavioral change
  - Entrepreneurial attitude
  - Integration/Coordination of policies
  - Finance, funding and risk management.

The matrix built for the study case of this thesis, contains recommendations quoted from publications by IEA, Sustainable Energy for All, IPCC, World Bank, European Commission, UNHABITAT, IPEEC, among others.

Energy Analysis

A key issue when designing energy policies is the selected energy accounting paradigm.. As stated before, major research and discussion on this topic have been done from the point of view of comparison and confrontation. Here is a proposal that tries to explode the main advantages of both accounting methods for develop a new paradigm of accounting capable to show the whole energy metabolism of the analyzed economy. In fact, looking with a scope that extends from the resource extraction to the final consumption of goods and services by individuals, the energy metabolism of a certain region could be described as shows the figure below. That figure reconciles both energy accounting paradigms thanks to the key factor of the energy extension vector (the exogenous resource vector in MRIO analysis). By using as energy vector in the CBA calculations the TFC per sector or the TPES per sector, it is possible to joint PBA and CBA and represent the whole energy metabolism, and furthermore, identify three kinds of trading involving energy: Trade of resources, intermediate production trade and goods and services trade as final demand. By using two novel IO approaches, it is possible to represent the supply and demand sides in CBA.

In our study case, due to the nature of the data used, the energy vector is composed by the TPES per sector, what means that losses and industry energy own use are also embodied in the goods and services production after the calculations of the CBA results. But if a TFC vector was used, losses and industry own use should be reflected before the union of both paradigms in its corresponding place. Depending on the result aggregation different insight on the obtained results can be performed. By means of result aggregation a wide bunch of energy maps showing the whole energy metabolism or a part of it (and always combining results of production-based and consumption-based accounting methods) can be performed by using the IEA standard definitions and the two matrices provided by the two MRIO non-conventional paradigms. In the list below the main and most useful energy maps is presented beside a brief description and explanation of each one.

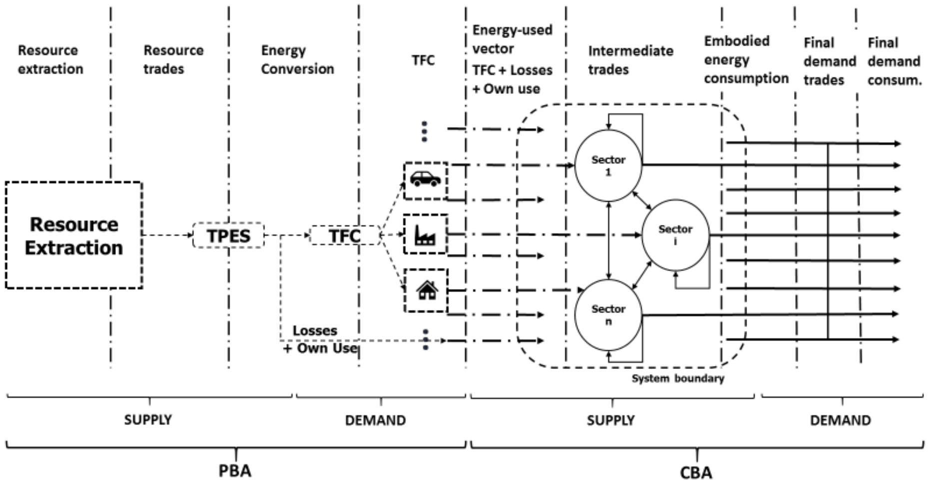

Figure 2. Joint use of PBA and CBA.

- Global energy map

The highest level of aggregation. This map represents the whole energy metabolism from a global perspective. Data for the extraction of resources is extracted from IEA and reconciled with the energy vector used in CBA calculations (TPES) to fulfill the balance. This map reflects the global energy metabolism from the energy resource extraction to the final consumption of goods and services. It reflects the resource trading, the intermediate product trade, and the trade of goods and services for fulfill final demand. However, due to the big amount of countries and sectors, a certain level of aggregation is needed to be able to represent this kind of map (i.e. represent world regions, according to World Bank classification such as East Asia & Pacific, Latin America & The Caribbean, North America, Middle East & Northern Africa, Europe & West Asia, and Sub-Saharan Africa). This aggregation results in a loss of scope when looking for information for design national policies. This map reflects the Primary Production, TPES, embodied energy consumption by economic sectors and regions, and embodied energy consumption by individuals in every world region and the energy flows that relate them. Despite of the usefulness of this kind of map as a global energy view, it cannot be, obviously, used as tool for help policy makers since the level of aggregation is too high for provide practical information in that field.

- National energy map

To get more valuable information for the field of energy policy, it would be better to take the scope to a national or at least to a smaller regional level. The National Energy Map does that. The drawback or the price to pay to get this level of scope is that due to the lack of data regarding the origin/destiny of the energy resource import/exports, the step of the resource extraction and the resource trading cannot be showed with the actual databases available (however theoretically it could be determined). This map shows the TPES by sector (and the national TPES) for a certain country, facing it with the embodied energy consumption of the analyzed country, which highlights if the country is an "energy burner" (i.e. its TPES is higher than its embodied energy consumption) or an energy consumer (i.e. its embodied energy consumption is higher than its TPES). Furthermore, this map highlights the origin of the embodied energy consumed by its economic sectors (and obviously, the embodied energy consumed by its economic sectors itself), and the destiny (countries or regions) in where, the produced goods and services in the analyzed country, will be consumed as final demand, in terms of embodied energy. The map represents the energy flows relating these concepts. An interesting feature of this map is that it is possible to stablish a direct comparison between the TPES and the embodied energy consumption both at sectoral and national level, in that way it is feasible to see the differences between the energy "burnt" by each sector and the actual energy consumption considering direct and indirect requirements. The map also stablishes a ranking in terms of sectors regarding both the TPES and the embodied energy consumption, making easier to foreground energy hotspots within the economic sectors of the analyzed economy, furthermore, these hotspots are not restricted to the domestic metabolism since the contributions from abroad to the domestic energy metabolism are also showed. Consequently, some synergies between countries and sectors are exposed. This information could be crucial when regarding to international cooperation.

This map is built using the TPES allocated by sectors (from the energy extension vector). Depending on the level of aggregation, this map could highlight single nations or large regions formed by several countries.

- Sectoral energy map

This map goes in a deeper level in order to expose information regarding a single sector of a certain economy. Due to the nature of the map the primary production and transactions of energy resources cannot be showed here (It does not exist primary production at sectoral level). It is build using the sectorial TPES and facing it with its embodied energy consumption, in this way the analyzed sector could be classified as "energy invoker" (i.e. its TPES is smaller than its embodied energy consumption) or an "energy supplier" (its TPES is bigger than its embodied energy consumption). Thus, the economies and sectors providing the energy requirements needed by the sector are exposed, again showing the energy flows between sectors and economies. A ranking of sectors and economies providing energy to the analyzed sector is done, and in that way, is easier to identify energy hotspots at intra-sectoral level and also expose energy synergies with other sectors from abroad. Then, the destiny of goods and services produced by the analyzed sector to be consumed as final demand by individuals is showed in terms of embodied energy.

Furthermore, thanks to this approach and the energy maps, two new definitions of energy dependency (regarding energy security) can be stated, improving the usefulness of the results. If the conventional definition of energy dependency is set as *first-degree energy dependency* (i.e. dependency acquired by trading of raw resources such as coal, oil, or natural gas). Then is possible to state a *second-degree energy dependency* being the dependency that a country acquires with respect to other (or others) in terms of imported/exported embodied energy in goods and services in the intermediate trade between productive sectors in order to invoke the necessary inputs for fulfill their production, closely related with the supply side of CBA paradigm. And it is even possible to define a *third-degree energy dependency*, consisting in the dependency acquired in terms of energy embodied in goods and services traded between countries in order to satisfy final demand of individuals.

Study Case: Africa IEA

Finally, the methodology proposed is applied to the African continent (to keep the work in line with AEEP requirements for the benchmarking matrix, and because the developing world has a crucial role to play in achieving the sustainable development goals). So, the benchmarking research is done keeping in mind the African context, and taking as paradigmatic framework the EU policy model, and the policies and actions implemented in countries as India, China, or Latin American nations. Once the benchmarking process has been applied and the matrix fulfilled, the energy evaluation method proposed is applied to the 27 countries of Africa IEA (due to data availability), highlighting some interesting maps, and achieving some interesting conclusions.

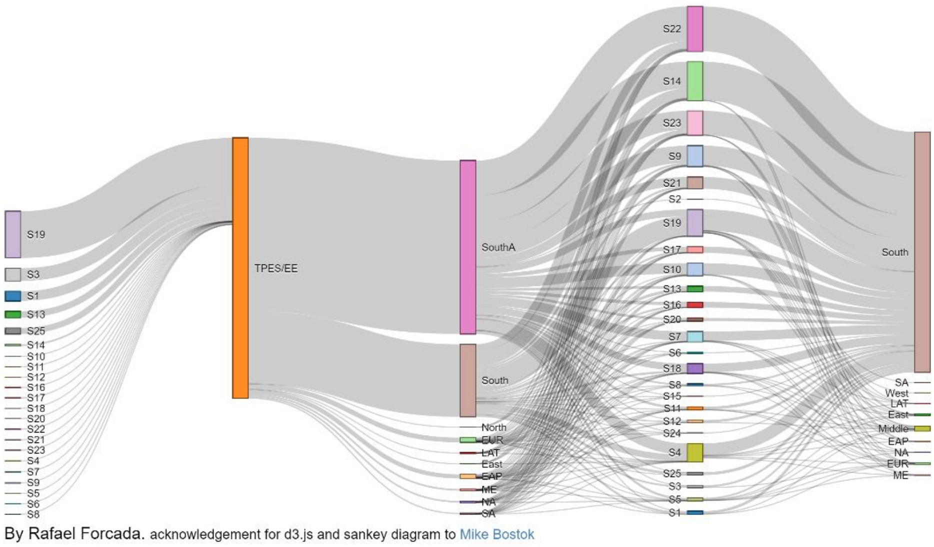

Figure 3. National Energy Map for Southern Africa (Botswana and Namibia).

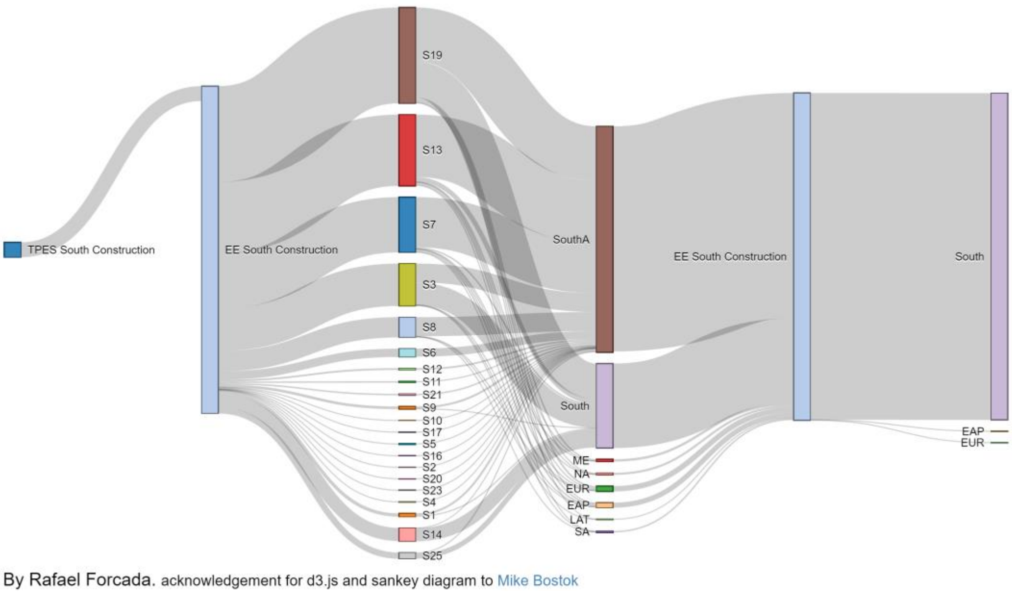

Figure 4. Sectorial Energy Map for Construction sector in Southern Africa.

Summarizing, South Africa is identified as the main responsible country for energy consumption in Africa, and increasing the scope of the analysis on this country, two sectors are listed as the main energy consumers in South Africa; Transport and Electricity, Gas & Water. These two sectors can be classified as energy burners (i.e. Their TPES is higher than their embodied energy consumption), and the same could be said of South Africa itself as a country. Using another approach of MRIO, Southern Africa sub-region (Namibia and Botswana) is identified as energy dependent with respect to South Africa. And effectively, if the National Energy map is analyzed for Southern Africa, it is revealed that its two main embodied energy consumer sectors (Construction and Public Administration), invokes most of its embodied energy consumed from South Africa Transport and Electricity, Gas & Water. So, we've identified two hotspots in the energy system, and also some synergies between economic sectors and/or countries. With this information, and always keeping in mind to promote international cooperation, stakeholder-action areas pairs are selected from the benchmarking matrix, for South Africa and Southern Africa (Botswana and Namibia), and with them the proper recommendations related, developing in that way a first draft of an energy strategy.

The thesis is structured as follows:

- In chapter one, an introduction and a literature review regarding energy accounting is presented. Here the usefulness and need of a methodology joining CBA and PBA is demonstrated.
- In chapter two, a conceptual model for identify stakeholders and action areas and relate them through specific energy policies, ideas, recommendations, etc. in a matrix, through research in specialized literature in a sort of benchmarking process is stated.
- In chapter three a theoretical and mathematical description of the developed model is done. Also, the paradigm of Energy Maps and how to build them and use them is explained here. Finally, it contains a guide, explaining the energy analysis algorithm involving the PBA-CBA method and the benchmarking matrix, in order to design a preliminary energy strategy.
- Point number four presents the Study Case of Africa. In this point, the African case is presented, and the methodology proposed applied. The results achieved are an insight of the several levels that could achieve the model, and the usefulness of the conclusions extracted: Hotspots and energy synergies are identified and related to specific policy recommendations in order to have a first draft or an energy strategy involving and enhancing international cooperation.

Resumen extendido

La comprensión, la cuantificación y la representación de la energía primaria suministrada y demandada por los sectores de las economías nacionales es hoy en día crucial para los responsables de formular políticas para definir políticas eficaces y fijar adecuadamente los objetivos de eficiencia energética y ahorro energético. La contabilidad energética basada en el tradicional paradigma basado en la producción (PBA) permite entender cómo la energía primaria es extraída, comercializada, transformada y utilizada directamente dentro de cada economía. Por otra parte, la contabilidad de la energía basada en el consumo (CBA) permite entender los propósitos económicos últimos de tales flujos de energía. Por lo tanto, la información proporcionada por la aplicación conjunta de estos enfoques puede aportar información útil y complementaria sobre la economía global, permitiendo identificar hotspots para posibles intervenciones tanto desde el punto de vista de la oferta como de la demanda. Este trabajo presenta un método que analiza y representa el metabolismo energético de las naciones, basado en un marco input-output multi-regional, teniendo en cuenta la energía fósil no renovable, a saber, el crudo, el carbón y el gas natural. La investigación se basa en los datos de la IEA y en la base de datos EORA26, considerando el año 2013. A partir de los resultados de un análisis convencional basado en la producción, se propone un método para descomponer la energía incorporada en bienes y servicios que permite cuantificar la energía directa e indirectamente invocada por los sectores económicos de las diferentes naciones analizadas para producir la demanda final. Por el contrario, desde el lado de la demanda, el modelo tradicional de Leontief permite dar cuenta de la energía incorporada en los productos consumidos como demanda final por cada economía. Por último, los resultados del análisis se reconcilian con el fin de proporcionar lo que los autores llaman Mapas energéticos, que reflejan tanto conteo energético PBA como CBA.

Introducción.

Como señalan la IEA y otras organizaciones, la eficiencia energética se está convirtiendo en un tema crucial en la formulación de políticas energéticas tanto a nivel nacional como internacional, será un punto clave para alcanzar los objetivos de cambio climático fijados en la COP21 en París. Los argumentos a favor y en contra de las políticas de mejora de la eficiencia energética han sido realizados por investigadores basados principalmente en el llamado efecto rebote (*rebound effect*), por el cual una mejora en la eficiencia energética tendrá como consecuencia una disminución del precio unitario de la energía, lo que provoca un aumento en el consumo de energía debido a la elasticidad precio característica de los servicios energéticos. Sin embargo, la mayoría de publicaciones coinciden en que, si bien el efecto de rebote es un hecho, no es lo suficientemente crítico para provocar efectos negativos como consecuencia de mejoras en la eficiencia. Por consiguiente, al promover el uso responsable de los recursos, es posible destacar las tendencias del uso de la energía y el crecimiento económico e incluso la tendencia creciente de las emisiones de CO2. De este modo, se podrían extraer dos beneficios diferentes: un ahorro económico (seguridad energética, creación de empleo, aumento de la productividad, etc.) y otro medioambiental (cambio de combustibles fósiles a energías renovables, disminución de emisiones nocivas), mientras se cumplen los principales objetivos hacia el desarrollo sostenible.

Mejorar la eficiencia energética en las economías nacionales.

La mayor parte de la literatura relacionada con la eficiencia energética está relacionada con el estudio, cuantificación y análisis del llamado efecto de rebote, es decir, discutiendo si las mejoras en la eficiencia energética son buenas o finalmente malas debido a efectos de segundo orden. A pesar de ello, es posible encontrar algunas definiciones interesantes para la eficiencia energética en publicaciones científicas.

Oikonomou et al. establecen una diferenciación interesante entre la eficiencia energética, que asocian con las mejoras tecnológicas y el progreso; y el ahorro de energía, es decir, un uso responsable por los consumidores finales, y por lo tanto, relacionado con el comportamiento de los usuarios finales y las reducciones de la demanda final. Arbex y Perobelli hacen una nueva diferenciación que relaciona la eficiencia con el origen de los recursos energéticos (es decir, renovables, no renovables, combustibles fósiles, etc.). Así, a partir de ahora, es apropiado hablar de mejoras del rendimiento energético hacia el desarrollo sostenible, y clasificarlas como mejoras de eficiencia (tecnología), ahorro de energía (demanda) y cambio de uso de recursos (producción). Por lo tanto, tres formas diferentes de actuar en los sistemas de energía con el fin de alcanzar los objetivos de desarrollo sostenible.

En cuanto a los métodos para cuantificar o analizar, Tanaka et al. Proponer varios indicadores basados en la contabilidad de la producción (es decir, teniendo en cuenta sólo los requerimientos energéticos directos) de la energía y la termodinámica. Para evitar el hecho de tener en cuenta sólo las necesidades energéticas directas es necesario introducir modelos Input-Output (IO), basados en la teoría de Leontief, como lo hacen Guevara et al. Que utilizan análisis IO para extraer varios indicadores relativos al rendimiento energético. Sin embargo, el modelo planteado por Guevara no permite hacer distinciones entre los lados de la demanda y la oferta, haciendo imposible tener una indicación sobre las políticas apropiadas para aplicar el sistema energético. Sin embargo, toda la literatura parece centrarse en discutir si la eficiencia energética de la energía es beneficiosa o no, y medir, cuantificar o definir indicadores del desempeño energético en las economías nacionales. No hay estudios sobre cómo identificar y localizar puntos críticos en los que aplicar esfuerzos con el fin de lograr mejoras energéticas y proporcionar información a los encargados de formular políticas sobre la cuestión del uso eficiente de los recursos energéticos; ni un enfoque que analice y destaque las relaciones y sinergias entre los países y los sectores económicos en términos de energía incorporada. En este trabajo, se propone un enfoque novedoso en un marco de IO, en combinación con las contabilizaciones basadas en la producción (PBA), con el objetivo de proporcionar información sobre dónde y cómo aplicar esfuerzos (y por lo tanto, presupuesto) hacia la mejora del rendimiento energético (eficiencia técnica, ahorro de energía y tipo de recurso utilizado) para lograr el mayor potencial de mejora y los mayores beneficios en términos de energía.

Contabilidad energética basada en la producción y el consumo.

Un problema crítico al tratar de cuantificar o medir la eficiencia energética es la contabilidad energética. En 1997, la UNFCCC en Kyoto definió el método contable para las emisiones de GEI como basado en la producción. A partir de entonces, ese método ha sido seguido por la mayoría de las organizaciones e investigadores, como la IEA. Básicamente, el modelo consiste en cuantificar la energía por medio del lugar de producción de recursos (producción primaria), luego reflejando las importaciones / exportaciones de recursos crudos, estableciendo el *Total Primary Energy Supply* (TPES), que después de las pérdidas de descuento en los procesos de conversión y uso propio de la industria, se convierte en el *Total Final Consumption* (TFC), el cuál es la energía consumida por los principales sectores que conforman la economía nacional. El método PBA presenta algunas ventajas importantes, como reflejar el origen de la producción de recursos energéticos, el comercio internacional de recursos energéticos crudos y las pérdidas en los procesos de conversión de energía. Sin embargo, también tiene inconvenientes importantes. Al buscar reducciones de emisiones, las políticas basadas en la PBA podrían dar lugar a fugas de carbono, y al desplazamiento de las actividades contaminantes de los países desarrollados a los países en desarrollo, y al contabilizar la energía, algunas actividades con pequeñas necesidades energéticas directas podrían tener importantes requerimientos energéticos “ocultos” o indirectos, como ocurre en la industria de la construcción. Esto podría engañar a los responsables políticos al diseñar estrategias energéticas. Por último, la energía embebida en los intercambios internacionales no se refleja, por lo que es imposible analizar los vínculos energéticos entre las naciones más allá del comercio de recursos crudos.

Por otro lado, existen los métodos de contabilidad basada en el consumo (CBA). Estos métodos se basan en el modelo productivo de Leontief. mediante un marco de input-output, las necesidades energéticas directas e indirectas se asignan adecuadamente a los sectores o países. El CBA es cada vez más relevante en política y en la toma de decisiones ya que las economías modernas son complejas y están globalmente vinculadas, haciendo de los sistemas energéticos y las políticas energéticas una cuestión global. La principal ventaja de este enfoque es la veracidad de las necesidades energéticas (y la responsabilidad por el consumo de energía) ya que se consideran tanto los requisitos directos como los indirectos. La energía embebida en los intercambios internacionales también está expuesta y, por consiguiente, las políticas basadas en CBA no se verán afectadas por el fenómeno de fuga de carbono. Este método de contabilidad ayuda a aclarar las responsabilidades en el consumo de energía, tanto entre los países como entre los sectores económicos. El principal inconveniente relacionado con CBA es sobre los datos. Para desarrollar este método de contabilidad, se requieren tablas de IO y los resultados se obtienen después de un cálculo más o menos complejo. Dos problemas surgen de ello, primero la falta de datos o la escasa precisión de los datos en las tablas de IO y, en segundo lugar, la incertidumbre resultante relacionada con el proceso de cálculo y la fiabilidad de los datos. El segundo inconveniente importante de la CBA está relacionado con la aplicación práctica de las políticas energéticas, que deberían definirse a nivel mundial mediante complejos acuerdos de política internacional. De hecho, la asignación de responsabilidades de CBA en términos de emisiones (comúnmente traducidas en impuestos a la exportación), suele traer preocupaciones distributivas y resistencia política. Autores como Jakon, Steckel y Edenhofer han afirmado que para resolver estas cuestiones, las medidas comerciales deben complementarse con alguna forma de asignación gratuita de permisos de emisión, así como enfoques sectoriales, que necesitarían cooperación y acuerdos internacionales. Otro punto importante es establecer el tipo de recursos a ser contabilizados y el límite de espacio para la contabilidad. Dado que la política energética es una preocupación mundial, la frontera de control del análisis debe establecerse a nivel mundial, sin embargo, la lógica pretende establecer sub-fronteras espaciales en las fronteras territoriales nacionales de cada país. En aras de la simplicidad, la frontera de análisis también podría circunscribirse a regiones multinacionales.

La respuesta a la cuestión de qué recursos deben contabilizarse depende del tipo de encuesta o del tipo de políticas que se apliquen. Puesto que en este trabajo estamos buscando mejoras de eficiencia hacia el desarrollo sostenible; Beneficios económicos; Y los problemas medioambientales, los recursos contabilizados se limitan estrictamente a los combustibles fósiles (es decir, carbón, gas natural y petróleo). Además, los combustibles fósiles representan más del 80% de la producción mundial de energía y el suministro total de energía primaria (TPES). Además, los combustibles fósiles son los principales responsables de las emisiones relacionadas con los GEI. De esta manera, es posible establecer tres indicadores energéticos diferentes en relación con los puntos calientes energéticos: Producción Primaria (que indica para la producción o extracción de recursos), TPES (que declara para la energía "quemada") y consumo de energía incorporado La energía realmente consumida). En la siguiente figura se observan las diferencias entre cada indicador de energía en varias regiones del mundo. De estas diferencias y de la definición de cada indicador pueden extraerse algunas conclusiones interesantes. Por ejemplo, qué regiones son los principales exportadores / importadores de combustibles fósiles, en qué regiones se consume principalmente la energía y dónde se consume directa e indirectamente.

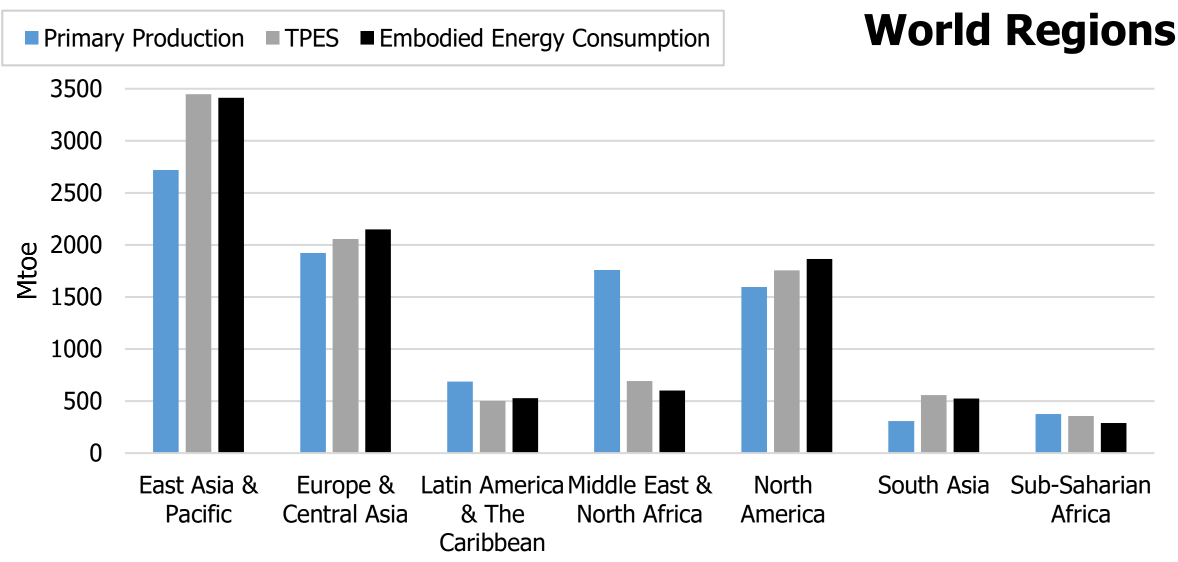

Figure 5. Diferentes métodos de conteo de energía.

Objetivo del trabajo.

En consecuencia, se identifican y tratan de satisfacer las siguientes necesidades a lo largo de este trabajo

1. Modelos para buscar hotspots en sistemas energéticos, buscando información sobre dónde aplicar esfuerzos hacia mejoras energéticas.
2. Modelos que dividan el sistema en el lado de la demanda y la oferta, para poder cuantificar los vínculos y las relaciones entre el sector económico y los países con el fin de encontrar sinergias en el diseño de las políticas energéticas.
3. El uso conjunto de los paradigmas basados en la producción y el consumo en un único modelo contable, para poder aprovechar las principales ventajas de ambos enfoques.

A continuación, los principales objetivos de esta investigación pueden enumerarse como sigue:

- Proponer un método basado en modelos basados en la producción y el consumo para comprender mejor el metabolismo energético de las economías nacionales a diferentes escalas (nacional y sectorial)
- Dividir el CBA en el lado de la oferta y la demanda y encontrar relaciones energéticas entre sectores y países.
- Identificar las principales partes interesadas y áreas de acción, y relacionarlo con las tres definiciones de mejora del rendimiento energético (eficiencia energética, ahorro de energía, uso de recursos).

Para mostrar un ejemplo de la aplicación y utilidad de este tipo de metodología, se aplicará a un estudio de caso. En cuanto al problema de las fugas de carbono y la creciente importancia de los países en desarrollo en la perspectiva energética mundial, se puede fijar un objetivo adicional:

- Aplicar dicho método al continente africano, identificando hotspots energéticos para mejorar la eficiencia energética, y relacionándolos con intervenciones específicas.

Esta investigación contribuye a la literatura de varias maneras: en primer lugar, se presenta un método para el uso de PBA y CBA, proponiendo una idea para un uso conjunto de ambos métodos de contabilidad que permite a los investigadores representar y analizar todo el metabolismo energético de cierta economía. En segundo lugar, mediante la utilización de enfoques no regionales convencionales de insumo-producto (MRIO), la oferta y la oferta se distinguen en la ACB, destacando los distintos tipos de vínculos entre los sectores económicos y / o los países. Esto facilita la identificación de hotspots y sinergias al hacer políticas hacia la mejora del sistema energético. Por último, se propone lo que el autor define como Mapas de Energía, con el fin de proporcionar una forma gráfica de presentar los resultados anteriores en un informe energético o en el asesoramiento de responsables políticos. Los mapas de energía admiten varios niveles de agregación (de un sector económico global a otro nacional) y, dependiendo de él, se proporcionan diferentes informaciones útiles para la formulación de políticas.

Métodos y modelos

Matriz Benchmarking

Una cuestión muy importante al diseñar las políticas energéticas o las estrategias energéticas es poder identificar a los actores implicados y lograr una adecuada coordinación y cooperación entre ellos. Este es el objetivo de la Matriz de Benchmarking. Esta matriz conceptual, construida y pensada por el requisito de la Asociación de Energía de la Unión Africana-UE AEEP () Eficiencia Energética Workstream y utilizado en esta tesis, se relaciona con diferentes partes interesadas con las áreas de acción a través de intervenciones energéticas extraídas de la literatura. Las partes interesadas forman las filas de la matriz, y las zonas de acción las columnas. Por lo tanto, cada zona de acción de partes interesadas de par contiene algunas recomendaciones de energía relacionadas con ellos. Este proceso debe llevarse a cabo teniendo en cuenta el contexto de las economías analizadas y los objetivos de la encuesta (lo mismo para la identificación de las partes interesadas).

En este trabajo, los interesados identificados se pueden enumerar como sigue.

- Sector Público:
    - Local
    - Regional
    - Nacional
    - Internacional
- Sector Privado:
    - Pequeña y Mediana Empresa (PYMES)
    - Grandes Empresas
- Sociedad Civil:
    - Organizaciones sin ánimo de lucro
    - Organizaciones con ánimo de lucro
- Academia
- Investigación:
    - Publica
    - Privada
- Ciudadanos individuales

Y las áreas de acción:

- Cadena energética:
    - Recursos energéticos

- Conversión energética
- Transmisión y distribución
- Aparatos de consumo y edificaciones

- Cuestiones transversales
    - Políticas
    - Formación
    - Cambios en el comportamiento
    - Actitud emprendedora
    - Integración y coordinación de políticas
    - Finanzas, inversions y gestión del riesgo..

La matriz construida para el estudio de esta tesis contiene recomendaciones de publicaciones de la IEA, SE4All, IPCC, Banco Mundial, Comisión Europea, UNHABITAT, e IPEEC, entre otros.

Análisis de energético

Un aspecto clave en el diseño de las políticas energéticas es el paradigma de contabilidad energética seleccionado. Como se ha señalado anteriormente, se han realizado importantes investigaciones y discusiones sobre este tema desde el punto de vista de la comparación y la confrontación. He aquí una propuesta que intenta explotar las principales ventajas de ambos métodos contables para desarrollar un nuevo paradigma de contabilidad capaz de mostrar todo el metabolismo energético de la economía analizada. De hecho, con un alcance que se extiende desde la extracción de recursos hasta el consumo final de bienes y servicios por parte de individuos, el metabolismo energético de una región puede describirse como muestra la siguiente figura. Esta cifra concilia ambos paradigmas de contabilidad energética gracias al factor clave del vector de extensión energética (el vector de recursos exógenos en el análisis MRIO). Utilizando como vector de energía en los cálculos CBA el TFC por sector o el TPES por sector, es posible unir PBA y CBA y representar todo el metabolismo energético, y además identificar tres tipos de comercio que involucran energía: Comercio de recursos intermedios El comercio de producción y el comercio de bienes y servicios como demanda final. Mediante el uso de dos nuevos enfoques IO, es posible representar la oferta y la demanda en el CBA.

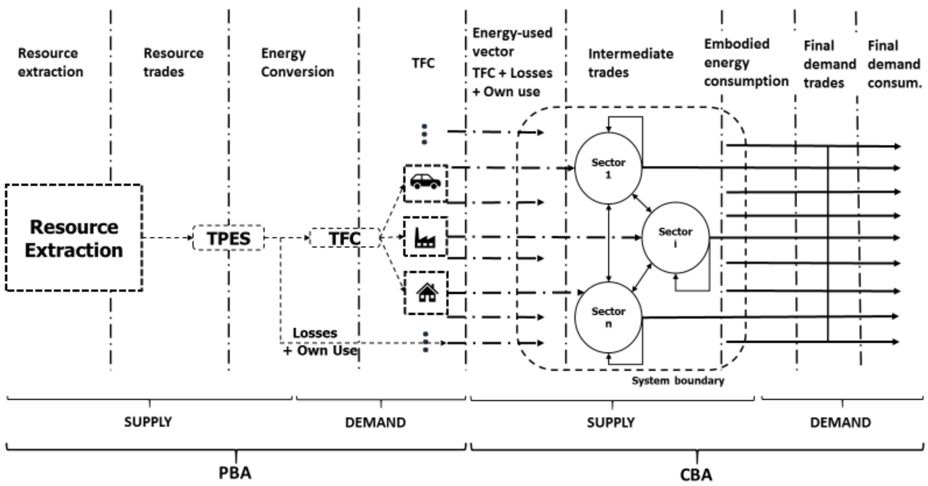

Figure 6. Uso conjunto de ambos paradigmas.

En nuestro caso de estudio, debido a la naturaleza de los datos utilizados, el vector de energía está compuesto por los TPES por sector, lo que significa que las pérdidas y el uso propio de la energía de la industria también se incorporan en la producción de bienes y servicios después de los cálculos de los resultados del CBA. Pero si se usara un vector TFC, las pérdidas y el uso propio de la industria deberían reflejarse antes de la unión de ambos paradigmas en su lugar correspondiente. Dependiendo de la agregación de resultados se puede realizar una visión diferente de los resultados obtenidos. Mediante la agregación de resultados, se puede realizar un amplio conjunto de mapas de energía que muestran todo el metabolismo energético o parte de él (y siempre combinando los resultados de los métodos de contabilidad basados en la producción y el consumo) utilizando las definiciones estándar de la IEA y las dos matrices Proporcionados por los dos paradigmas no convencionales de MRIO. En la siguiente lista se presentan los principales y más útiles mapas de energía, junto con una breve descripción y explicación de cada uno.

- Mapa energético global

El nivel más alto de agregación. Este mapa representa el metabolismo energético total desde una perspectiva global. Los datos para la extracción de recursos se extraen de la IEA y se reconcilian con el vector de energía utilizado en los cálculos CBA (TPES) para cumplir el balance energético. Este mapa refleja el metabolismo energético global desde la extracción de los recursos energéticos hasta el consumo final de bienes y servicios. Representa el comercio de recursos, el comercio de productos intermedios y el comercio de bienes y servicios para satisfacer la demanda final. Sin embargo, debido a la gran cantidad de países y sectores, se necesita un cierto nivel de agregación para poder representar este tipo de mapa (es decir, representar regiones mundiales, de acuerdo con la clasificación del Banco Mundial como Asia Oriental y Pacífico, América Latina y el Caribe). Caribe, Norteamérica, Oriente Medio y Norte de África, Europa y Asia Occidental y África subsahariana, en lugar de países). Esta agregación resulta en una pérdida de alcance y enfoque cuando se busca información para diseñar políticas nacionales. Este mapa refleja la Producción Primaria, TPES, consumo de energía incorporado por sectores económicos y regiones, y consumo de energía incorporado por los individuos en cada región del mundo y los flujos de energía que los relacionan. A pesar de la utilidad de este mapa como una visión global de la energía, no puede usarse, obviamente, como herramienta para ayudar a los responsables de la formulación de políticas, ya que el nivel de agregación es demasiado alto para proporcionar información práctica en ese campo.

- Mapa energético nacional

Para obtener información más valiosa en el ámbito de la política energética, sería mejor llevar el ámbito de aplicación a un nivel nacional o, al menos, a un nivel regional más reducido. El Mapa Energético Nacional hace esto. El inconveniente o el precio a pagar para obtener este nivel de enfoque es que debido a la falta de datos sobre el origen / destino de la importación / exportación de recursos energéticos, el paso de la extracción de recursos y el comercio de recursos no puede mostrarse con las bases de datos disponibles actualmente (sin embargo, teóricamente se podría representar). Este mapa muestra las TPES por sector (y las TPES nacionales) para un país determinado, enfrentándolo con el consumo de energía embebida TEES del país analizado, lo que pone de manifiesto si el país es un "quemador de energía" (es decir, su TPES es superior a su TEES) o un consumidor de energía (es decir, su TEES es superior a su TPES). Además, este mapa destaca el origen de la energía consumida por sus sectores económicos y el destino (países o regiones) en donde, los bienes y servicios producidos en los sectores del país analizado, se consumirán como demanda final, en términos de energía embebida. El mapa representa los flujos de energía que relacionan estos conceptos. Una característica interesante de este mapa es que es posible establecer una comparación directa entre el TPES y el consumo de energía incorporado tanto a nivel sectorial como nacional, de esta manera es factible ver las diferencias entre la energía "quemada" por cada sector y el consumo real de energía considerando los requerimientos directos e indirectos. El mapa también establece un ranking en términos de sectores, tanto en lo que respecta a los TPES como al consumo de energía embebida, facilitando la identificación de los hotspots de energía en los sectores económicos de la nación analizada, además estos hotspots no están restringidos al metabolismo doméstico ya que las contribuciones desde el extranjero al metabolismo energético doméstico también se muestran. En consecuencia, algunas sinergias entre países y sectores están expuestas. Esta información podría ser crucial para incentivar la cooperación internacional.

Este mapa se construye utilizando los TPES asignados por sectores (del vector de extensión de energía). Dependiendo del nivel de agregación, este mapa podría resaltar naciones únicas o grandes regiones formadas por varios países.

- Mapa energético sectorial

Este mapa va a un nivel más profundo con el fin de exponer información sobre un único sector de una cierta economía. Debido a la naturaleza del mapa, la producción primaria y las transacciones de los recursos energéticos no pueden mostrarse aquí (no existe la producción primaria a nivel sectorial). Se construye a partir del TPES sectorial que se contrasta con su consumo de energía embebida, de esta manera el sector analizado podría ser clasificado como "invocador de energía" (es decir, su TPES es menor que su consumo de energía incorporado) o un "proveedor de energía" TPES es más grande que su consumo de energía embebida). A continuación, se exponen las economías y sectores que aportan los requerimientos energéticos necesarios del el sector, mostrando de nuevo los flujos de energía entre sectores y economías. Se realiza una clasificación o ranking de los sectores y economías que suministran energía al sector analizado, y de esta forma es más fácil identificar los hotspots energéticos a nivel intra-sectorial y también se exponen sinergias energéticas con otros sectores del extranjero o domésticos. Luego, el destino de los bienes y servicios producidos por el sector analizado para ser consumidos como demanda final por los individuos se muestra en términos de energía embebida en ellos.

Además, gracias a este enfoque y a los mapas energéticos, se pueden enunciar dos nuevas definiciones de dependencia energética (con respecto a la seguridad energética), lo que mejora la utilidad de los resultados. Si la definición convencional de dependencia energética se establece como *dependencia energética de primer grado* (es decir, la dependencia adquirida mediante el comercio de recursos crudos como el carbón, el petróleo o el gas natural). Entonces es posible afirmar que una *dependencia energética de segundo grado* es la dependencia que un país adquiere con respecto a otro (u otros) en términos de energía embebida importada / exportada en bienes y servicios en el comercio intermedio entre sectores productivos cuando invoca los inputs necesarios para poder llevar a cabo su producción, este tipo de dependencia está estrechamente relacionada con el lado de la oferta del paradigma del CBA. También es posible definir una *dependencia energética de tercer grado*, consistente en la dependencia adquirida en términos de energía incorporada en bienes y servicios comercializados entre países para satisfacer la demanda final de los consumidores finales.

Caso de Estudio: Africa IEA

Por último, la metodología propuesta es aplicada al continente africano (para mantener el trabajo en línea con los requerimientos del AEEP para la matriz de benchmarking y porque el mundo en desarrollo tiene un papel crucial en el logro de los objetivos de desarrollo sostenible). Por lo tanto, la investigación de benchmarking se realiza teniendo en cuenta el contexto africano y tomando como paradigma el modelo de política de la UE y las políticas y acciones implementadas en países como India, China o naciones latinoamericanas. Una vez que se ha aplicado el proceso de benchmarking y se ha cumplimentado la matriz, el método de análisis energético propuesto se aplica a los 27 países de Africa IEA (debido a la disponibilidad de datos), destacando algunos mapas interesantes y obteniendo conclusiones relevantes en materia de política energética.

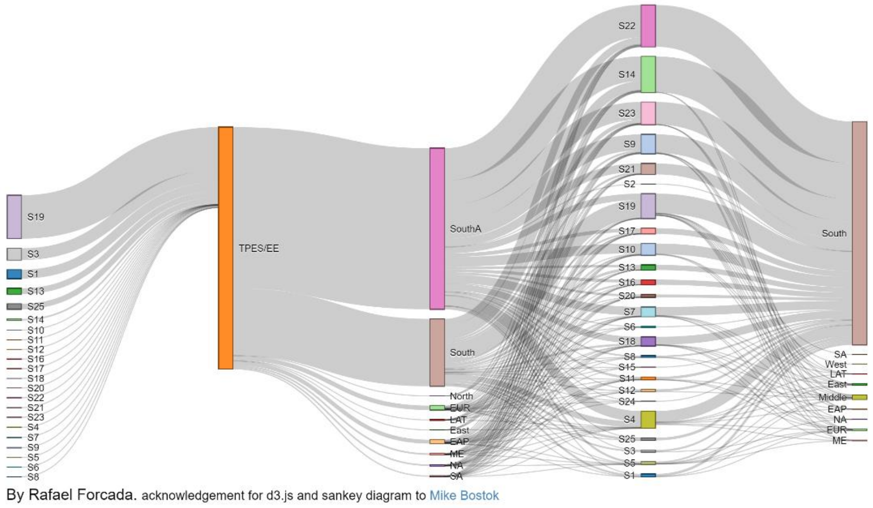

Figure 7. Mapa energético nacional para el sur de África (Namibia y Botswana)

En resumén, Sudáfrica se identifica como el principal país responsable del consumo de energía en África, y aumentando el alcance del análisis en este país, dos sectores se enumeran como los principales consumidores de energía en Sudáfrica; Transporte y Electricidad, Gas y Agua. Estos dos sectores pueden clasificarse como quemadores de energía (es decir, su TPES es más alto que su consumo de energía incorporado), y lo mismo podría decirse de Sudáfrica como un país. Utilizando otro enfoque de MRIO, la subregión de África meridional (Namibia y Botswana) se identifica como dependiente de la energía con respecto a Sudáfrica. Y efectivamente, si se analiza el mapa de la energía nacional para el sur de África, se revela que sus dos principales sectores de consumo de energía incorporados (construcción y administración pública), invoca la mayor parte de su energía incorporada consumida de Sudáfrica Transporte y Electricidad, Gas y Agua. Así, hemos identificado dos hotspots en el sistema energético, y también algunas sinergias entre sectores económicos y / o países. Con esta información y siempre teniendo en cuenta para promover la cooperación internacional, las parejas de las áreas de acción de los actores se seleccionan de la matriz de evaluación comparativa para Sudáfrica y África meridional (Botswana y Namibia), y con ellas las recomendaciones apropiadas relacionadas desarrollándose de esa manera Un primer borrador de una estrategia energética.

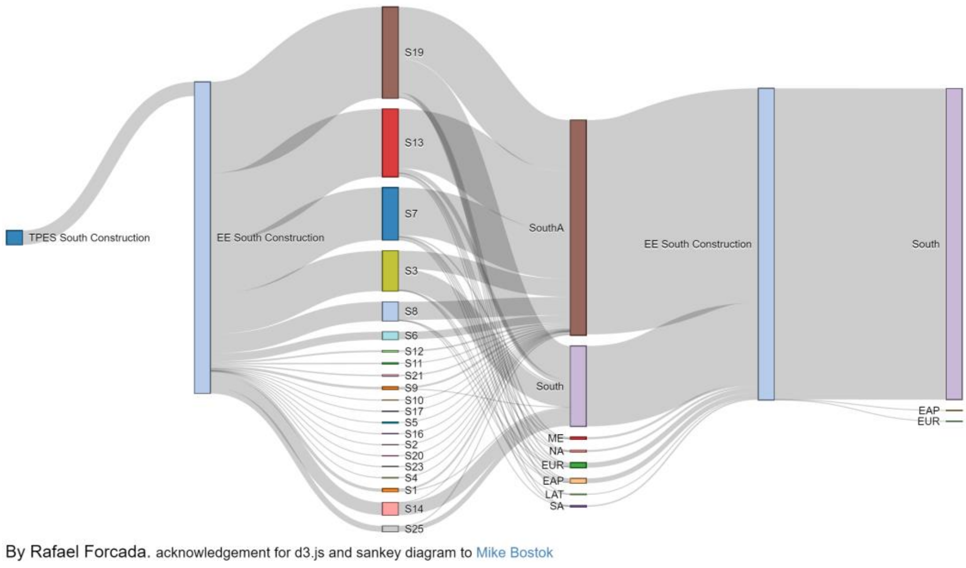

Figure 8. Mapa energético sectorial para el sector de la Construcción en el sur de África.

La tesis se estructura de la siguiente manera:

- En el capítulo uno se presenta una introducción y una revisión de la literatura sobre contabilidad energética. Aquí se demuestra la utilidad y necesidad de una metodología para unir CBA y PBA.
- En el capítulo dos se presenta un modelo conceptual para identificar actores y áreas de acción y relacionarlas a través de políticas energéticas específicas, ideas, recomendaciones, etc. en una matriz, a través de la investigación en literatura especializada en una especie de proceso de benchmarking.
- En el capítulo tres se realiza una descripción teórica y matemática del modelo desarrollado. También se explica el paradigma de los Mapas de Energía y cómo construirlos y usarlos. Finalmente, contiene una guía, explicando el algoritmo de análisis de energía que involucra el método PBA-CBA y la matriz de benchmarking, con el fin de diseñar un primer borrador de estrategia energética.
- El capítulo número cuatro presenta el Caso de Estudio de África. En este punto, se presenta el caso africano y se aplica la metodología propuesta. Los resultados obtenidos son una visión de los diversos niveles que podría alcanzar el modelo y la utilidad de las conclusiones extraídas: Hotspots y sinergias energéticas son identificados y relacionados con recomendaciones políticas específicas para tener un primer borrador de una estrategia energética que involucre diversos sectores económicos y países e incentive cooperación internacional.

Contents

1 Introduction

1.1 Efficient use of energy resources at national level

The unstoppable trend of population growth [1] and the proved evidence of the link between economic growth and energy consumption [2–4], puts pressure on the earth's finite resources and ecosystem capacity. Consequently, efficient use of energy resources and reduction of harmful emissions have become an important issue in most of political agendas around the World, e.g. efficient use of resources is the "heart of the EU's Europe 2020 Strategy for smart, sustainable and inclusive growth and the transition to a resource efficient economy" [5]. Policy-makers and all the actors with a stake in the energy sector need to have well-based information about the scenario and context that they are trying to modify. Regarding the recent concerns about global warming [6] and energy security [7], this need is becoming more important year by year. The fact that most of policy-makers and decision-takers related to the energy sector have no technical formation, highlights the need (and the difficulty) of provide such information in a comprehensive and simplified way. Because of that, it is important for us, engineers and technicians trying to find our role as policy-makers advisors, to build a bridge of communication and understanding that helps to fulfill that need. Energy resources are defined by Merriam-Webster Dictionary as *"a fundamental entity of nature that is transferred between parts of a system in the production of physical change within the system and usually regarded as the capacity for doing work"*. An energy resource is the first step in the chain that supplies energy services, it can be classified as renewable (from sources that replenish themselves naturally) and non-renewable (from sources which don't replenish naturally), the latter can be distinguished as fossil fuels (coal, oil and natural gas) and nuclear energy (the source that exploits the energy stored in the nuclei of particles). Enhancing energy resource efficiency means taking actions towards save energy and finding ways to generate energy services at lower environmental costs, renewable energies will therefore play an increasing important role in future energy scenarios.

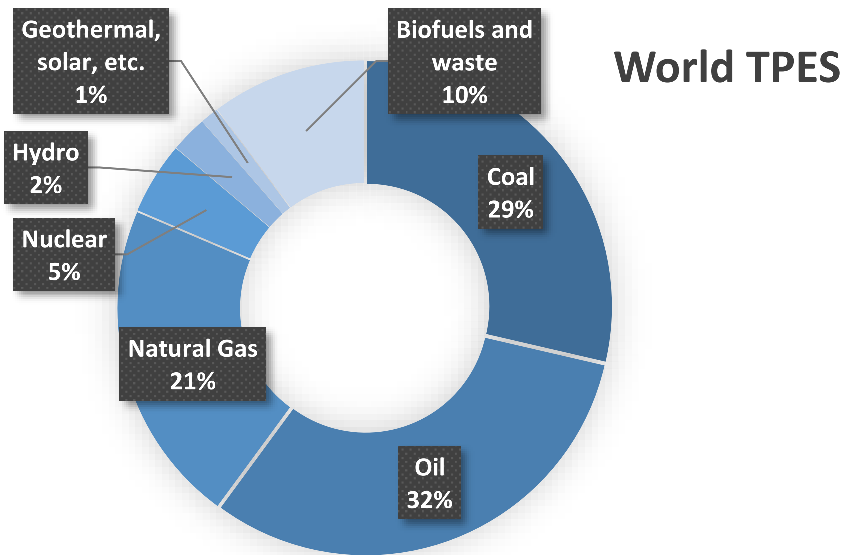

Figure 9. *World Total Energy Supply by source, data from IEA.*

Since fossil fuels are (because of their chemical composition and the way to exploit the energy contained by them i.e. mainly combustion) the main cause of harmful emissions (also being responsible of most of green-house gas emissions (GHG) such as CO2 [8]), and they account for more than the 80% of the energy consumed by the World economy, this survey is focused on such kind of energy resources. Fossil fuel resources are also critical related to the energy security issue. Since the fossil fuel reserves distribution around the World is biased and depends completely on natural and geographical factors, it is possible to find countries with huge reserves and countries with a lack of it, which translates in important energy dependencies between countries and regions [9]. Furthermore, instability of oil prices is a common source of economic shocks that affects other sectors in a negative way, or oppositely, a financial crisis could affect oil prices which leads to a more serious situation [10–12].

Efficient use of fossil fuel resources is not only a crucial factor for economic and environmental issues across all economies, but also, as states the International Energy Agency (IEA) [13], it could provide multiple benefits to many different stakeholders. Efficient use of energy resources is a major contributor to strategic objectives across three main themes: economic development (orange in the figure), sustainability and environmental protection (green in the figure), and prosperity and social development (blue in the figure). The figure below represents the main areas around which an improvement on the efficiency in using energy resources could

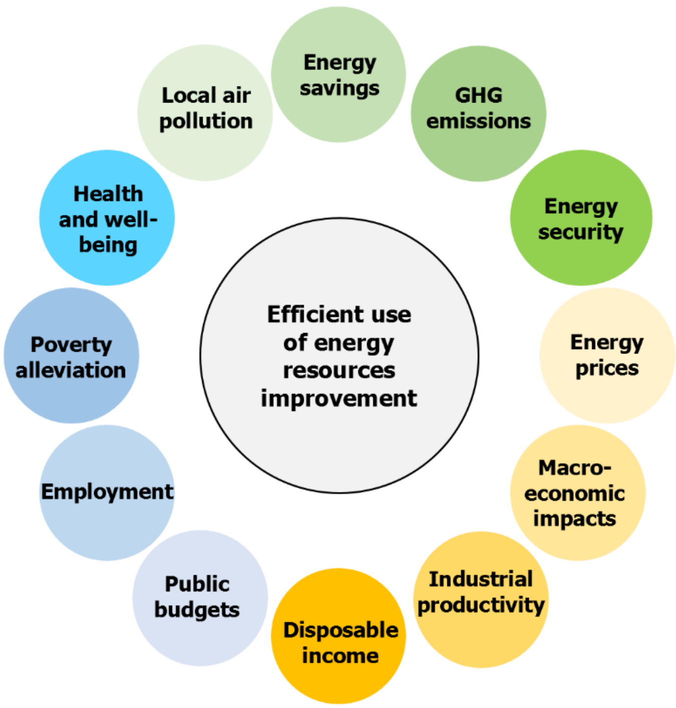

Figure 10. *Multiple benefits from an efficient use of energy resources improvement*

bring related benefits. Energy efficiency (from now, synonym of efficient use of energy resources) could cause a positive impact from a macro-economic perspective in direct and indirect ways, increasing economic activity with job creation, improving trade balance or decreasing energy prices. It could also represent an impulse to public budget by reducing government expenditures on energy, by reducing fossil fuel imports or by the reduction in the budget for unemployment payments when energy efficiency policies lead to job creation [14]. Industrial productivity is a benefit too, since industry often views energy as an operational cost, energy savings are perceived as incidental benefits. When applied to buildings, or regarding the decrease in local air pollution, efficient use of energy resources improvements, create conditions that support improved citizen health and well-being, such as an enhance on physical health and comfort [15]. Consequently, realized health and well-being improvements generate downstream social and economic impacts, including lower public health spending. Through employment creation, reduction in energy prices and improving energy access, efficient use of energy resources is also a focus of poverty alleviation. Finally, the two main or direct benefits derived from an improvement on the efficiency of fossil fuels use, are the energy savings (and consequently the improvement in energy security of a nation when reducing its fossil fuels import), and the reduction in GHG emissions, but also in local air pollution. These multiple benefits of reduce consumption of fossil fuels are in line with most of the targets of UN Goals for Sustainable Development [16], and with the Paris Agreement set in COP21 [17], in this way is easy to understand and see the importance of achieve improvements on the efficient use of energy resources in the following years.

By the way, what we should understand by “efficient use of energy resources”? The concept of efficiency commonly refers to the ratio of benefits to expenses. Therefore, energy efficiency refers to the ratio between the benefits gained (not necessarily measured in terms of energy), and the energy used to provide such benefits. Energy efficiency concept can be then applied to different contexts: (a) energy efficiency in the macro-economic perspective of national economies (b) energy efficiency of energy conversion devices; and (c) energy efficiency related to the end-uses on the demand side, achieved by technical, organizational, institutional, structural or behavioral changes [18]. A wide range of energy efficiency definitions can be retrieved in literature: among others, Patterson defines a series of indicators used to measure energy efficiency from the economic and the physic perspectives, focusing on the direct consumption of energy caused by economic segments at national level [19]. Oikonomou et al. distinguish among *energy efficiency* and *energy saving* interventions: the former is the result of a technical improvement, while the latter is related to the end-user’s behavior and the reduction of final demand of energy products [20]. Other methods have been reviewed by Tanaka et al., which recognize different indicators, such as the absolute energy consumption, the energy intensity, the diffusion of specific energy saving technology and the thermal efficiency [21]. Other authors, however, present more critical approaches regarding energy efficiency mainly based on the so called rebound effect [22–24]. Horace Herring, one of the authors more critical with energy efficiency, states that the proper policies to be applied to reduce fossil fuel consumption need to be focused in shift the energy resource to a renewable paradigm instead to apply efforts in energy efficiency. Nevertheless most authors conclude that while rebound effect is a fact, it is not negative enough to make energy efficiency improvements to have an overall negative effect [25–27]. Summarizing, according to literature, it is possible to find three ways for a more efficient use of energy resources, or in other words reduce fossil fuel consumption:

- *Technical efficiency:* Involves a technological improvement on energy conversion or production process, achieving the same outputs using less energy. An energy efficiency improvement will help to decouple economic growth from energy use, and also energy use from CO2 emissions.
- *Energy savings:* Involves a decrease on final consumption, reducing final demand is possible to achieve a more responsible use of resources. Closely related to end-users’ behavior.
- *Resource origin:* Involves the change of energy resource used to a more sustainable and environmental-friendly one (e.g. begin to heat water with solar thermal panels instead of using a coal or gas boiler). A change in resource use towards renewable energy sources, will help to decouple energy use from CO2 emissions.

These three ways of achieving improvements in the efficient use of energy resources involve actions on different steps of the energy chain, and therefore very different policies to be implemented, which will achieve success or not depending on the characteristics of the energy scenario that policy-makers are trying to modify. Consequently, it is easy to see the importance of have policy-makers fully aware about “how”, “who” and “where” act and about the consequences of their actions. For that reason, arises the importance to proper identify the main stakeholders in the energy sector (i.e. who will be the main actors beside an energy policy? And what can they do for the energy policy to succeed?), the action areas that should be covered or intervened by a policy (i.e. in which part of the energy chain is better to act? How is better to act in order to achieve the final target?), and to locate and quantify the energy hotspots in which the higher energy benefits could be achieved (i.e. Where is better to apply efforts? In which country? In which region? In which economic sector?). The need of identifying and quantifying energy hotspots shows a problem that usually face energy policy-makers and/or advisors: The energy accounting issue.

1.2 The energy accounting issue

A critical issue in quantifying the energy consumption of production activities resides in the choice of the appropriate energy accounting method. In general, energy requirements of one generic system can be evaluated based on the *Production-based accounting* (PBA) or the *Consumption-based accounting* (CBA) paradigms. Applications of PBA and CBA are usually focused on the accounting of non-renewable energy resources (namely raw coal, crude oil and natural gas). Beside the issue of resources scarcity, fostering an efficient and rational use of non-renewable energy resources is relevant, since they provide more than 80% of the whole global energy production, resulting as the major responsible for GHG and pollutants emissions [28,29]. Considering one generic national economy, PBA quantifies the *Total Primary Energy Supply* (TPES) through the algebraic sum between the primary energy produced by the considered national economy and the energy imports/exports, which after discount losses on conversion processes and industry own uses, turns into the *Total Final Consumption* (TFC), defined as the energy directly consumed by industries and households [30]. PBA approach has been adopted to account for national energy consumption and GHG emissions by most statistics organizations, including International Energy Agency and British Petroleum, and it has assumed by the Kyoto Protocol as the standard method to account for and to determine the responsibility for CO2 emissions at national level [31,32]. On the other hand, CBA aims to account for the energy directly and indirectly consumed by industrial activities to support the production of goods and services ultimately consumed by households as final demand (i.e. the *energy embodied* in goods and services). CBA are usually based on macroeconomic models, and Leontief's Input-Output models among others. Recently, Afionis et al. reviewed advantages and drawbacks of the use of PBA and CBA, revealing that CBA is becoming increasingly relevant for policy-making, since it allows to understand the drivers for primary energy consumption, providing estimations of the energy effects due to structural changes within the economy[33]. PBA accountings are able to reflect the actual path of energy resources, including production, international trades, and losses taking place in conversion and transmission processes. However, PBA does not allow to understand the full scope of the energy production and conversion chain, since the link between energy production and the consumption of goods and services is missing. Due to this fact, PBA policies defined in the past years was responsible for environmental leakages, giving place to the displacement of pollutant activities from developed to developing countries [34,35]. On the other hand, regarding policies based on CBA, the allocation of responsibilities in terms of emissions (commonly traduced on export taxes), usually brings distributional concerns and political resistance. Authors like Jakon, Steckel and Edenhofer have stated that in order to solve these issues, trade measures should be complemented with some form of free allocation of emission permits as well as sectoral approaches, which would need international cooperation and agreements [36]. Consequently, it is possible to find a research gap in the energy accounting topic, looking for a new methodology able to joint both paradigms in a comprehensive way, explaining the relation and the transition from PBA to CBA, in order to keep policy-makers fully informed. The knowledge about the energy consumed by countries and sectors, and how it is distributed in goods and services exposing energy relationships, will be the first step to understand the current energy scenario and therefore to design the best energy policies.

1.3 Objectives

For all the stated before, the following needs or research gaps are identified:

- Identification of the possible main stakeholders and action areas related to the energy sector, and specially related to the policy or strategy to be designed
- Identification of energy hotspots which could represent urgent needs of energy regulations, but also the best opportunities for energy interventions.
- Reconcile both energy accounting paradigms (PBA and CBA) in order to try to exploit their advantages and the useful information provided by both.

Consequently, the main goal of this work could be defined as the development of a framework or methodology for comprehensive energy assessment of nations or regions, using PB and CB accountings in a combined way in order to provide information to policy-makers; identify main stakeholders and action areas regarding the energy scenario; expose energy hotspots, and energy links between economic sectors and countries; and provide a comprehensive and simplified output which should be useful in the process of design of energy policies or energy strategies. In order to fulfill such goal, a list of specific activities will be developed:

- The construction of a Benchmarking Matrix. This conceptual matrix will have two purposes. In first place, it should identify and list the main stakeholders and action areas related to the energy scenario. In second place, it should relate them through a benchmarking process. By research in specialized literature, each stakeholder and action area will be related with ideas, recommendations, energy policies proposed or already developed, etc.
- Propose an energy accounting method that combine PBA and CBA results, in order to take advantage of both methodologies and to be able to expose energy hotspots and energy relationships between countries and sectors.
- Develop an algorithm that provides an output complementing the results of the accounting method and the benchmarking matrix. This output should be useful to provide information to policy-makers in a comprehensive way and a practical input for the first steps of the design of a new energy policy or a new energy strategy.
- As a possible future work, but out of the scope of this work, a first insight of a methodology for model mathematically the energy policies or interventions and forecast and analyze their impact on the energy scenario and the economy.

In the figure X the structure of the previously described activities is graphically explained. First, thanks to the benchmarking matrix, stakeholders and action areas in the energy scenario are identified and related by means of ideas, recommendations and policies, it is a first approach to answer the questions "Who? Where? And How?". Secondly, both energy accounting paradigms are applied in a jointed with the clear intention of expose energy hotspots by representing and assessing the energy metabolism of the analyzed economy, but also to highlight the energy relationships or energy dependencies between countries or regions, and between economic sectors. The result of this methodology will bring technical insight to the answers to "Who? Where? And How?", furthermore, this information will be a technical back-up for the benchmarking process. Combining both by means of an algorithm a first draft of an energy strategy could be achieved. Despite this draft cannot be considered as a complete strategy ready to be applied, it will be a useful input for the design of the final strategy to be followed by a country or region. Finally, the last step would be to analyze and forecast the impact and implications of such energy strategy.

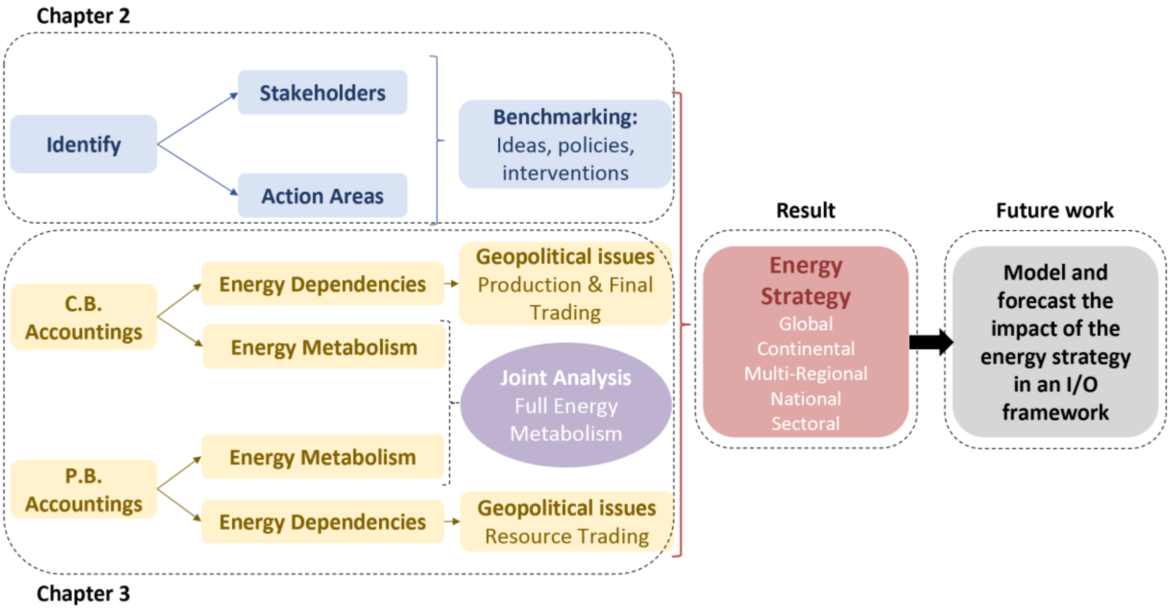

Figure 11. *Work structure*

1.4 Structure of the thesis

In this section, the structure of the thesis is briefly explained and summarized.

Chapter 2: The Benchmarking Process

This chapter explains the process for developing the benchmarking matrix. Explaining the main idea beside it, then proceeding with the identification of both Stakeholders and Action Areas and their definitions and making clear about the energy actions that are related to each couple.

Chapter 3: Energy Accountings

In this chapter, the energy accounting issue is discussed. Firstly, a literature review of PBA and CBA is included, and both methods are explained. Secondly, the theoretical basis of the novel paradigms used in the methodology proposed are stated, highlighting their usefulness and the information provided by each one. Thirdly, the joint use of PBA and CBA is discussed, and the concept of the "Energy Maps" (A graphical/numerical representation of the energy metabolism of regions, countries and even economic sectors) is introduced. This concept will be further developed in order to introduce a new definition of different degrees of energy dependency among countries, strictly related to different stages of trade. Lastly, with the purpose of providing the proper output from the combination of the benchmarking process and the energy accounting paradigms, an algorithm or methodological step-guide, is introduced.

Chapter 4: Study Case: Africa IEA

The methodological framework has been tested through an application to the Africa IEA countries (i.e. countries for which the Agency provides energy data). First, a research on literature has been done looking for possible policies and energy interventions that could fit for the African countries (which are mainly undeveloped and developing countries). Secondly, both PBA and CBA are applied to 27 African countries (from now Africa IEA), following the classification and the assessments made by Colombo et al. [37], and using IEA [28] and EORA26 [38,39].

Chapter 5: Conclusions and main achievements

In this chapter, the main conclusions and achievements of this work are listed and discussed. It also includes a small dissertation about possible future work or research, including the possibility of developing a framework for mathematically model energy policies and strategies in order to be able to analyze and forecast their impact and consequences from an energy but also an economic point of view.

2 Benchmarking process

In order to be able to design a good energy strategy, first of all is necessary to have a clear and wide vision of the actors or stakeholders involved on it [37,40], but also of the key action areas on which one intervention is possible, recommendable or even profitable. Engagement, consultation and dialogue between the main actors involved in the energy sector are remarked and boosted by organizations such as the IEA [7,41] or the EU [42,43]. Such organizations made a clear point on the importance of cooperation between groups of regulators, industry and other stakeholders on one hand, and the meaningful involvement of local communities, civil society and other institutions on the other hand. The stakeholder identification will clarify the main responsible of the different tasks necessary to the success of an energy intervention. Furthermore, a proper identification of actors will expose some stakeholders that in a first insight appear to be irrelevant but at the end could help substantially to deploy such energy interventions. On the other hand, to have a clear knowledge on the action areas will help to clarify and understand in which parts of the energy chain is proper to act, and what issues and complementary areas are also relevant from an energy point of view. Action areas should not be focused just on the energy sector or the energy supply chain, but other social and economic areas in which relapse quite important issues closely related to energy improvements [44].

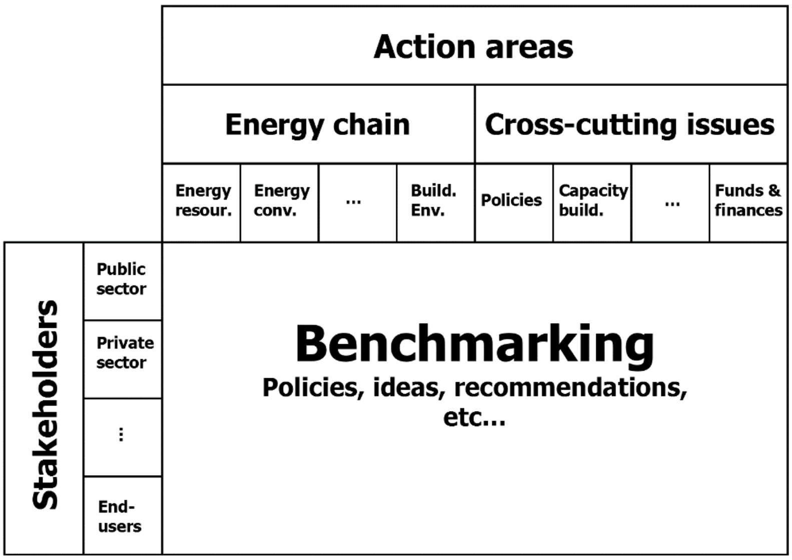

Figure 12. *Benchmarking matrix*

The benchmarking process is built around a matrix (the Benchmarking Matrix). The columns of this matrix will represent the different action areas, while the rows will contain the stakeholders. In this way, each stakeholder is related to each action area by one cell of the matrix. Then, by research in specialized literature, each cell is filled with ideas, recommendations or energy policies and intervention already applied somewhere, related with each couple stakeholder-action area. A first and similar attempt to relate action areas and stakeholders could be seen in SE4All (Sustainable Energy For All) Global Action Agenda [45]. The idea of applying benchmarking technics to the energy sector is neither new, for example in [46], Jamasb and Pollit propose a benchmarking for regulation issues in electricity distribution sector. The main objectives of such a matrix are to promote cooperation and communication between the main players on energy efficiency, and to analyze strategies, policies and actions for each identified stakeholder on how to promote efficient use of energy resources based on previous findings and ideas successfully applied or recommended.

2.1 Stakeholders identification

In this section, the main stakeholders related to the energy sector and present on the matrix are listed, described and explained.

Public Sector: It refers to public institutions, governments and agencies. This embraces from international organizations formed by several countries, like EU or the UN, to little town municipalities. The important relevance of this stakeholder is due to the fact that they manage the legislative framework and, consequently, they have the power to introduce new policies or change the existing ones. Furthermore, they manage the Public budget, a crucial issue when financing energy efficiency. Since "Public sector" is a very wide sector, it would be proper to split it into a list of sub-sectors regarding geographical reasons, but also taking into account the classical hierarchy of governments or organizations.

- Local: Public sector at local level includes town halls, mayoralties, neighborhood associations coordinated by town hall, and public services and administration at urban level. It has the closest contact to specific projects and issues, its area of influence its limited to urban regulations.
- Regional: It involves regional governments which have in charge several towns and cities, and they are capable of coordination tasks at intermediate level. One of its main capabilities is the coordination and supervision of the Local level.
- National: Referred to the central government of each country and the head of state office. Possibly the most important one. They have most of the legislative and executive power; and they will be the main managers of national budget too. The public sector at national level is the main responsible of any political action, while the other levels act more like help and assistance.
- International: Implies multi-national associations and organizations, which involves governments, or representation of governments, from several countries. It also attempts to involve bi-lateral agreements for cooperation between countries toward energy efficiency.

Private Sector: It refers mainly to private companies and organizations pursuing private interests. They are not under direct control of governments, however it is possible to condition their behavior through laws and regulations by means of Pigouvian taxes, incentives, command and control measures, subsidies, assignment of property rights and bargaining among others [45]. Nevertheless, there is no need for private companies to be drag by public sector since big gains from efficient use of energy resources are expecting for them if they show a wise behavior investing in energy efficiency. Profitable business opportunities will appear if private companies take the initiative towards energy efficiency and responsible use of energy resources. For a deeper understanding of energy scenario, and for taking into account the different capabilities, resources and energy intensity of different size companies this stakeholder is also divided into two sub-actors, regarding the size classification of private companies or organizations made by the EU Commission [46,47]:

- Small and Medium Sized Enterprises (SME's): According to the definition given by the European Commission, Small and Medium Sized Enterprises states for private companies with less than 250 employees. This kind of companies will, generally, have presence in a single or in a small number of countries. Because of that their relevancy as actors holds for regional and local levels mostly.
- Large Enterprises: It states for companies with a number of employees larger than 250. This kind of companies are most likely to have presence in a wide number of countries, and they can take leadership as energy actors also at local or regional level; but mainly at national and international level.

Civil Society: It comprises organizations and individual actors whose actions can have a greater influence or relevancy than actions of conventional individuals. This kind of actors cannot be classified as public nor private sector. It is the aggregate of NGO's and institutions that manifest interest and will of citizens. Civil Society is also divided among two sub-actors, in order to consider different purposes and motivations, organization structure, way of work, and the interest of this organizations or the spectra of society that they represent.

- Non-Profit organizations: It refers to NGO's, volunteer's associations, and organizations which mission is to help and to improve society regardless economic benefits. They could have a simple local implantation to a complex international presence.
- Profit organizations: It involves organizations, and associations that cannot be considered as part of public nor private sector, and are part of civil society, but also have economic interests beyond helping or improving society in a selfless way. Mass media, investors, or lobbies are part of this sub-actor.

Academia: Defined by Merrian-Webster Dictionary as "the life, community, or world; of teachers, schools, universities and education". It makes reference to the education institutions which main paper is the capacity building and spreading information.

Research: This stakeholder refers to every activity of investigation, surveys, think tanks and Research & Development (R&D) related to energy. Not only involves scientific research, but also humanistic (i.e. psychology research towards behavior changes) or economic research (i.e. marketing research for improvements of information campaigns or research for quantifying economic factors or effects as the rebound effect). In order to consider different research resources, different research motivations and different research fields, this stakeholder is also divided into two sub-actors:

- Public research: Referred to research funded by public budget, mainly research which takes place in universities and public institutions.
- Private research: Funded by private budgets, mostly by large enterprises. It looks for competitive advantages and economic profits. However, energy efficiency improvements usually bring advantages in which private companies are interested on.

Individuals: It refers to individual citizens as end consumers and users of energy and the actions that they can take, marginally, in order to follow the path towards a sustainable model of economy.

2.2 Action areas identification

For the action areas, a major classification is used, distinguishing among action areas belonging to the energy supply chain and action areas belonging to cross cutting issues.

2.2.1 Energy supply chain

Energy Resource: It alludes to the phase of resource extraction but also to the kind of resource used to provide energy (i.e. use coal or solar thermal panels for heating purposes). Primary energy is extracted or captured from different sources, and the physical and chemical characteristics of the energy is not changed, such as for hard coal directly extracted from the ground [48].

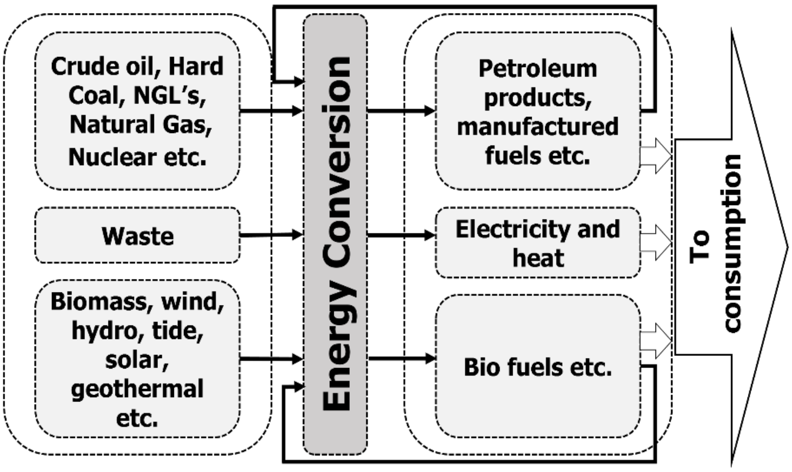

Figure 13. *Energy resource and Energy conversion*

Energy Conversion: It refers all the processes and machinery involved on energy transformation into more useful forms or to goods, services and utilities.

Transmission and Distribution: Defined as the infrastructures and methodologies used for taking or deliver energy or energy resources from suppliers to consumers in different phases of the energy chain.

End-User devices and Building Environment: It involves all the domestic or commercial machines and devices that consumes energy for provide a direct service or good to final users (i.e. lighting, computers, cars, trains, mobile phones, refrigeration systems, …). And the issues related to energy efficiency related to buildings (isolation, heating and cooling systems, pumping, electric panels, …).

2.2.2 Cross cutting issues

Policies: Governmental or corporative actions, laws, regulations, etc. Looking for push a change in a specific direction. Characterized by set precise goals, and the proper way to achieve it. Implemented besides control and monitoring programs, which provide feedback and data used for correct possible design mistakes. It mainly acts at national level; however regional and local administration are indispensable for a proper implementation; and the cooperation of several countries t international level, for shake of unity and coherence of actions, improves and makes easy the success of implemented policies.

Capacity Building: Is a conceptual approach to social or personal development that focuses on understanding the obstacles that inhibit people, governments, international organizations and non-governmental organizations from realizing their development goals while enhancing the abilities that will allow them to achieve measurable and sustainable results. Focused on improvement of leadership skills, institutions know-how, access to knowledge and formation, labor force specialized skills, etc. [49].

Behavioral Change: Referred to change in consumption habits, not only for individuals, but also for companies and institutions. A lot of potential improvements exists in the ways that energy is used and consumed; quite far away from optimality [50–52].

Entrepreneurial Attitude: Initiative, innovation, fresh ideas, among other characteristics of entrepreneurial attitude, have been proved to have a positive benefit when progress enhancement is sought, especially in energy issues [53,54].

Integration and Coordination of Policies: It is a quite important action area, since, once designed, a proper implementation [55], and a good coordination between the different stakeholders involved in any manner with it, is essential for achieve success and targeted goals.

Finance, Funding and Risk Management: According to the IEA, the potential size of global investment opportunities for energy efficiency was estimated at USD 310 billion in 2016, and is growing every year [15]. Recognizing this, more and more governments and financial institutions have given energy efficiency finance a high priority. The volume of capital investment into energy efficiency has accelerated, investments have become increasingly incentivized, and a growing number of financial innovation measures have begun to develop in this area [56,57]. This volume of capital investment is non-assumable for governments and public funding alone, so attracting private capital and investors is a crucial issue in order to achieve energy efficiency development.

3 Energy Accountings

3.1 Consumption Based & Production Based

Due to the objective of the Climate Change Convention (UNFCCC) defined during the past decades, literature related to environmental accounting methods is mainly focused on GHG emissions [32]. However, emissions of pollutants and GHG and consumption of energy are highly related to each other, since almost all of non-natural CO2 emissions are produced by means of fossil fuels depletion. Production Based Accountings (PBA) have been established by almost all the authoritative international organizations (such as UNFCCC and IEA) as the official way to quantify pollutants, GHG emissions and energy consumptions, and it has been assumed by policy-makers to assess the responsibility of national economies in consuming primary resources or causing emissions [31]. However, recent researches on PBA highlighted several drawbacks concerning its use: Fujimori et al. [58] performed a critical review of IEA energy statistics based on PBA paradigm, highlighting the main issues and problems connected with their use and proposing a methodology to enhance the calculation of the World's industrial energy consumption. Moreover, Boitier provides evidences of the carbon leakage resulting from the use of PBA for designing emission control policies, which is due to the shift of the most carbon intensive industrial activities from domestic to foreign countries [34]. Policy development based on CBA has been proposed as a possible method to overcome such issue: Gemechu et al. present a way to implement a Consumption-based policy through an environmental tax based on the carbon footprint for the pulp and paper sectors, setting up the model based on results of LCA and Environmentally Extended Input Output analysis [59]. On the other hand, the research of Jakob et al. on the implementation of Consumption-based pricing policies have revealed that adding markups to products prices proportional to their embodied emissions does not necessarily correspond to a reduction of absolute national emissions, and they propose a tax on exports to alleviate distributional concerns and political resistance among other non-commercial actions [36]. Environmental policy definition based on the results of both PBA and CBA accounting methods have also been discussed: for instance, Peters has investigated the issue of carbon leakage connected with the use of both the emissions accounting methods, and proposes a model to share responsibility of emissions through the joint use of Consumption- and Production-based models [60]. Recently, Sakai et al. provide a broad discussion related to the use of PBA and CBA approaches for emissions policies: they have deepened the logic behind attributing responsibility for emissions on the basis of consumption instead of production, discussed the main arguments against consumption-based policies (mainly related to their implementation complexity and political acceptability), and finally presented a wide range of implementation possibilities in the current political framework [33].

While large amount of published researches can be easily found on GHG emission accountings, literature on of energy accountings is lagging behind, and it is mainly focused on the practical application of CBA for embodied energy accountings. Zhu Liu et al. propose the comparative application of PBA and CBA based on an Input-Output model, quantifying the direct and the embodied energy consumed by Chinese industries [61]. In the same vein, Hong et al. [62] performed an embodied energy analysis of the construction industry in different Chinese regions, ranking the regions based on their direct and embodied energy consumptions. Zhang et al. [63] performed an energy MRIO analysis of Chinese regions without focusing on a specific industry, but providing Sankey diagrams to identify the trades of embodied energy among regions. Along this research line, Zhang et al. [64] assessed the trades of embodied energy among Chinese regions based on a MRIO model in a time frame between 2002 and 2007, and both studies find considerable discrepancies between direct and embodied energy requirements of the analyzed contexts. Alcántara et al. [65] performed an embodied energy analysis of the Spanish key sectors, highlighting the possible energy hotspots in a CBA perspective.

A fewer number of theoretical developments in the application of CBA energy accountings can be found in literature. Owen et al. account for energy consumption of UK products in a CBA perspective, through the comparative application of Input-Output models based on different energy extension vectors, and discussing differences and possible fields of applications [66]. Sato et al. discuss possible way to decompose the aggregated value of embodied energy distinguishing the suppliers, thus discussing possible approaches to enhance the national energy security of supply [67]. Li et al. [68] performed an embodied energy analysis for the city of Beijing by proposing a Multi-scale input-output analysis, identifying the source of energy embodied in products consumed by Beijing citizens: local (directly consumed in the city), domestic (consumed in China) and foreign. Choi et al. [69] proposes an input-output framework to analyze the effects of energy taxes and subsidies on primary energy use, useful to analyze multiple and inter-related policy interventions. Rocco et al. analyze the uncertainty in embodied energy in goods and services comparing different methods to account for international trades in a Multi-Regional Input-Output framework [70]; the same authors provide a novel method to internalize the effect of human labor within the embodied energy of goods and services through an partially closed Input-Output model [71]. Finally, Su et al. [72] propose theoretical advances and practical applications of the Structural Decomposition Analysis (SDA) of energy and emissions based on a MRIO model.

3.2 Theoretical Basis

In this section, the main theoretical and mathematical principles of PBA and CBA are explained in a summarized way. There are also included some non-conventional approaches related to CBA that will be the bridge for a joint use of CBA and PBA. The issue regarding to the energy vector on CBA analysis is also studied. Results are used for providing new value to the methodology, giving geopolitical energy information towards enhance international cooperation among countries.

3.2.1 Production Based Energy Accountings (IEA Standards).

Some definitions are necessary for a clear statement, according to IEA standards [30].

- *Primary Production*, is the production of primary energy extracted from natural environment. It is calculated after removal of impurities (i.e. Sulphur in natural gas).
- *Imports and Exports*, make mention to amounts of resources that have crossed the national territorial boundaries, whether or not customs clearance has taken place.
    a) Oil and natural gas: Quantities of crude oil and oil products imported or exported under processing agreements (refining on account) are included. Quantities of oil in transit are excluded. Crude oil natural gas liquids and natural gas are reported as coming from the country where they were extracted; refinery feedstocks and oil products are reported as coming from the country of last consignment. Re-exports of oil imported for processing within bonded countries are shown as exports of product from the processing country to the final destination.

b) Import/export of coal comprise the amount of fuels obtained from or supplied to other countries, whether or not there is an economic or customs union between the relevant countries. Coal in transit not included.

c) Electricity is considered imported/exported when it has crossed the national territorial boundary.

- *International marine bunkers*, covers those quantities delivered to ships of all flags that are engaged in international navigation. Consumption by ships engaged in domestic navigation is not included. Domestic navigation is distinguished from International navigation in terms of port of departure and port of arrival. Consumption of fishing and military ships is also excluded.
- *International aviation bunkers*, covers the aviation fuels of aircraft in international aviation. International aviation is stated in terms of departure/arrival. Fuel consumption by road vehicles used by airlines is excluded.
- *Stock changes*, it reflects the differences between opening stock levels on the first day of the year and closing levels on the last day of the year on national territory held by producers, importers, energy transformation industries and large consumers. A stock build is shown as a negative number, and a stock draw as a positive number.
- *Transfers* includes interproduct transfers, products transferred and recycled products.
- *Total primary energy supply (TPES)* is made up of production plus imports subtracting exports, international marine bunkers, international aviation bunkers and stock changes. For the world total, marine and aviation bunkers are not subtracted.

$$TPES = Production + Imp. + Exp - M.Bunkers - A.Bunkers \pm Stock\ Changes \tag{3.1}$$

- *Statistical differences*, includes the sum of unexplained statistical differences for individual fuels, as they appear in the basic energy statistics. It also includes the statistical differences that arise because of the variety of conversion factors in the coal an oil columns.
- *Electricity plants* refers to plants which are designed to produce electricity only. If one or more units of the plant is a CHP unit (and the inputs and outputs cannot be distinguished on a unit basis) then the whole plant is designated as a CHP plant. Both main activity producers and autoproducer plants are included here.
- *Oil refineries*, shows the use of primary energy for the manufacture of finished oil products and the corresponding output. Thus, the total reflects transformation losses.
- *Other transformations* cover non-specified transformation not shown elsewhere, such as the transformation of primary solid biofuels into charcoal.

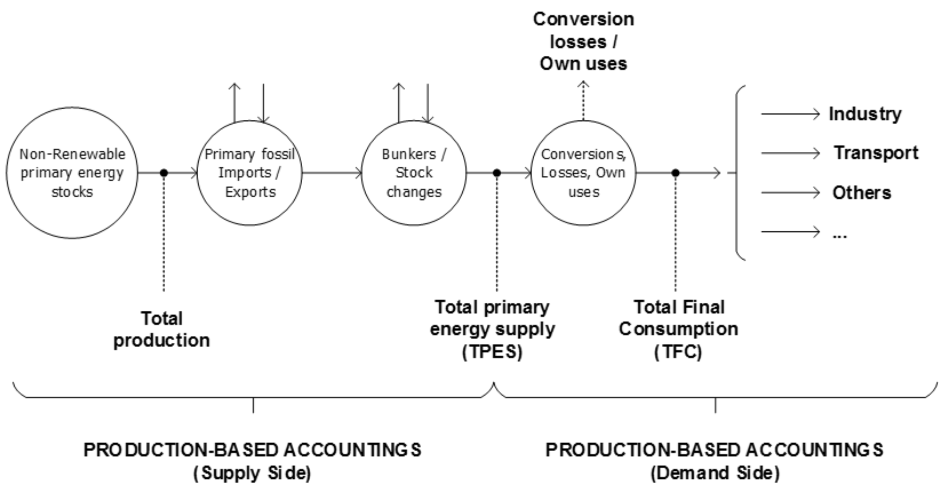

Figure 14. *Complete PBA diagram according to IEA Standards*

- *Energy industry* own use, is the primary and secondary energy consumed by energy conversion and transformation industries for heating, pumping, traction and lighting purposes.
- *Losses*, refers to losses in energy distribution, transmission and transport.
- *Total final consumption (TFC)* is the sum of consumption by the different end-use sectors. Backflows from the petrochemical industry are not included on final consumption. Balance could be used for providing a new definition of TPES by using TFC.

$$TFC = C_{Industry} + C_{Transport} + C_{Other} + C_{Non\_Energy\_Use} \tag{3.2}$$

$$TPES = TFC + \sum (Energy\_conversions + Own\_uses + Losses) \tag{3.3}$$

IEA Consum. sectors	***ISIC sectors*** [73]
Industry	• Iron and Steel Industry (ISIC G242 C2432) • Chemical and Petrochemical Industry (ISIC D20-21) (excluding petrochemical feedstocks) • Non-ferrous metals basic industries (ISIC G242 C2432) • Non-metallic minerals (ISIC D23) • Transport Equipment (ISIC D29-30) • Machinery (ISIC D25-28) • Mining (excluding fuels) and quarrying (ISIC D07-08 and G099) • Food and tobacco (ISIC D10-12) • Paper, pulp and printing (ISIC D17-18) • Wood and wood products (other than pulp and paper) (ISIC D16) • Construction (ISIC D41-43)

	• Textile and leather (ISIC D13-15) • Non-specified (any manufacturing industry not included above) (ISIC D22,31 and 32)
Transport	• Transport (ISIC D49-51) (Includes transport in industry and covers domestic aviation, road, rail, pipeline transport, domestic navigation and non-specified transport. Fuel used for ocean, coastal and inland fishing and military consumption are excluded from this category.
Other *Residential* *Commercial* *Public services* *Agriculture/fishing* *Forestry* *Non-specified*	• Residential, commercial and public services (ISIC D33, 36-39, 45-47, 52, 53, 55, 56, 58-66, 68-75, 77-82, 84 (excluding Class 8422), 85-88, 90-99) • Agriculture/Forestry (ISIC D01, 02) • Fishing (ISIC D03)
Non-energy use	(Covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel. Non-energy use also includes petrochemical feedstocks).

Table 1. *IEA sectors & ISIC sectors.*

3.2.2 Consumption Based Energy Accountings

Consumption-based accounting has an established methodology using Input-Output (IO) Tables. IO analysis is the name given to the analytical framework developed by professor Wassily Leontief, in recognition of which he received the Nobel Prize in Economic Science in 1973. The fundamental purpose of IO framework is to analyze the interdependence of industries in an economy. In its most basic form, an IO model consists of a system of linear equations, each one of which describes the distribution of an industry's product throughout the economy. The widespread availability of high-speed digital computers has made Leontief's input-output analysis a widely applied and useful tool for economic analysis at many geographic levels (local, regional, national, and even international). The model is widely applied throughout the world; the United Nations has promoted IO as a practical planning tool for developing countries and has sponsored a standardized system of economic accounts for constructing IO tables. Despite it is a tool of economic theory, it has been recently applied to technical and environmental issues, such as accounting or assess international and interregional flows of products and services or accounting for energy consumption and environmental pollution associated with interindustry activity. The fundamental information used in in IO analysis concerns the flows of products from each industrial sector, considered as a producer, to each of the sectors, itself and others, considered as consumers. This basic information from which an IO model is developed is contained in an interindustry transactions table. The rows of such a table describe the distribution of a producer's output throughout the economy. The columns describe the composition of inputs required by a particular industry to produce its output. The final demand refers to the sales by each sector to final markets for their production, such as personal consumption. For example, electricity is sold to business in other sectors as an input to production (an interindustry transaction) and also to residential consumers (a final demand trade). The mathematical structure of an IO system consists of a set of *n* linear equations with *n* unknowns, therefore, matrix representation can readily be used, as can be seen in the figure. An IO model is constructed from observed data for a particular economic area (a nation, a region (however defined), a continent, even the World economy). The economic activity in the area must be able to be separated into a number of segments or producing sectors. These may be industries in the usual sense (e.g., steel) or they may be much smaller categories (e.g., steel nails and spikes) or much larger ones (e.g., manufacturing). The necessary data are the flows of products from each of the sectors (as a producer/seller) to each of the sectors (as a purchaser/buyer). These interindustry flows, or transactions or intersectoral flows (the terms industry and sector are often used interchangeably in IO analysis) are measured for a particular time period (usually a year) and in monetary terms. While the physical measure is perhaps a better reflection of one sector's use of another sector's product, there are substantial measurement problems when sectors actually sell more than one product. For these and other reasons, then, accounts are generally kept in monetary terms, even though this introduces problems due to changes in prices that do not reflect changes in the use of physical inputs [74].

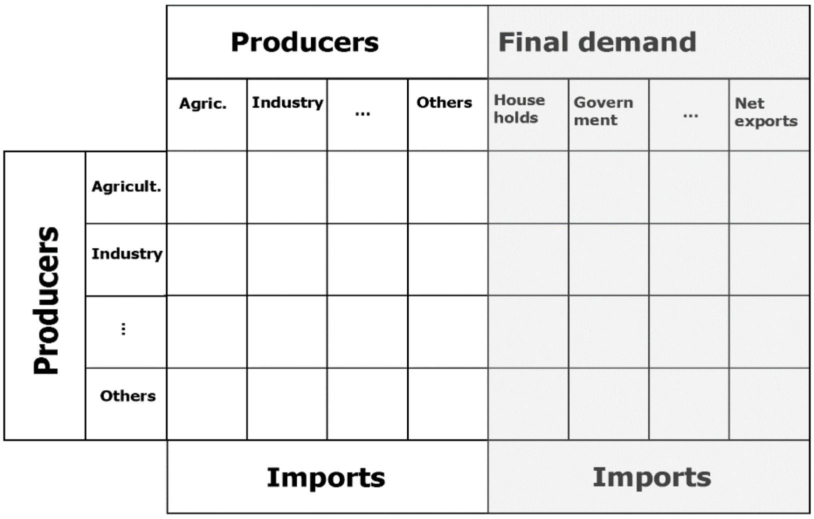

Figure 15. *IO table for interindustry transaction and final demand.*

There are additional rows, which account for the other (non-industrial) inputs to production, such as labor, depreciation of capital, and indirect business taxes. In general energy IO typically determines the total amount of energy required to deliver a product to final demand, both directly as the energy consumed by an industry's production process and indirectly as the energy embodied in that industry's inputs. In engineering parlance, calculating this total energy requirement is the result of what is often called a process analysis: a target product is identified either as a good or service, then a list can be compiled of the goods and services directly required to deliver the product. These inputs to the target production process include fuels (direct energy) and other non-energy goods and services. The non-energy inputs are then analyzed to determine the inputs to their production processes, which again include some fuels and nonenergy goods and services. This process analysis traces inputs back to primary resources; the first round of energy inputs is the direct energy requirement; subsequent rounds of energy inputs comprise the indirect energy requirement. The sum of direct and all indirect energy requirements comprise the total energy requirement. In this work, the framework used is the multi-regional input-output model. In the MRIO analysis, also known as multi-directional trades method, the territorial boundary embraces a group of several countries or regions. Each country has associated an endogenous interindustry transaction table $\mathbf{Z_{end,i}}$, but it has also associated *2N-1* (being *N* the number of countries or regions in the analysis) international transaction matrices $\mathbf{Z_{ij}}$, which represent the interindustry trades with other countries (intermediate imports and exports used as production inputs), the final demand table $\mathbf{f_w}$ has a similar issue, and includes international trades for fulfill final demand in other countries (imports and exports of goods and services destined to satisfy final demand). Consequently, the input-output tables for a MRIO analysis have the shape that can be seen in figure 12. If we define a table with *N* countries and *n* economic sectors per country, the total number of sectors in the global economy can be defined as $n_{tot} = N \cdot n$. And the total production vectors $\mathbf{x_{i\,(nx1)}}$ (which represent the total production of each sector in order to fulfill the production required as inputs by other sectors and the production consumed as final demand).

$$\mathbf{x}_i = \mathbf{Z}_{end,i} \cdot \mathbf{i} + \mathbf{f}_{end,i} + \sum_{j \neq i} \mathbf{Z}_{ij} \cdot \mathbf{i} + \sum_{j \neq i} \mathbf{f}_{ij} \tag{3.4}$$

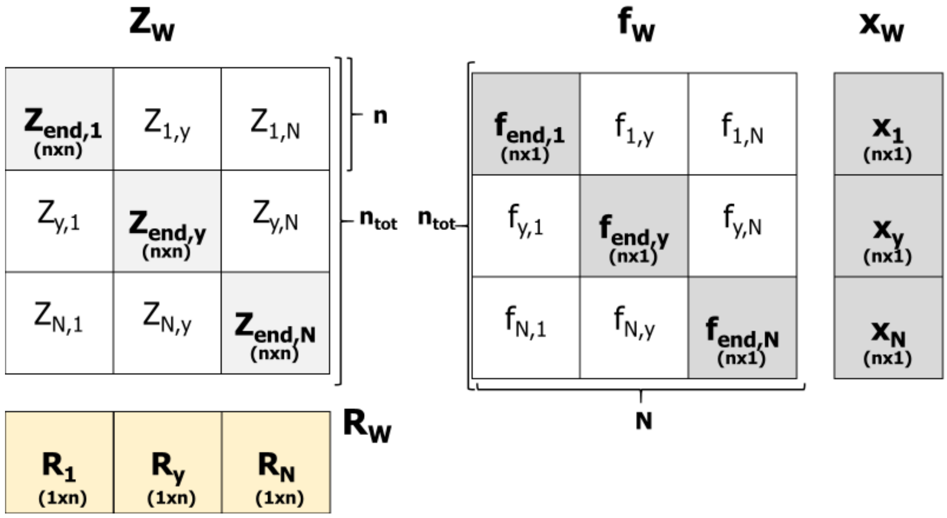

Figure 16. *IO table for interindustry transaction and final demand.*

With vectors $\mathbf{R_{i\,(1xn)}}$ being the exogenous energy resource vector. There are several ways to build vector $\mathbf{R_{i\,(1xn)}}$. In this work, the exogenous energy resource vector mainly used is built with the TPES per sector of each country, representing the direct fossil fuel related energy input for each industry. However, for one of the CBA paradigms, the vector is built by taking into account the fossil fuel primary production for each country and allocating it to the Mining & Quarrying sector. According to Anne Owen et al, this vector can be built even with the TFC per sector, and the goodness of each kind of energy vector depends on the kind of survey and the information that researchers are looking for [66]. Since we are using TPES per sector as energy vector, the industry own use energy and the energy conversion losses will be embedded in goods and services produced. Then, we have $\mathbf{Z_w}$, $\mathbf{f_w}$, $\mathbf{R_w}$, $\mathbf{x_w}$, the matrix system representing the MRIO tables, the math behind CBA calculations is easily explainable. Beginning with the definition of the matrix of technical coefficients:

$$\mathbf{A}_{n_{tot} x n_{tot}}; \quad \text{with} \quad a_{ij} = {z_{ij}}/{x_j} \tag{3.5}$$

According to the definition of $\mathbf{A_w}$ the multi-regional model can be built as:

$$\mathbf{x}_w = \mathbf{A}_w \mathbf{X}_w + \mathbf{f}_w \cdot \mathbf{i} \qquad (3.6)$$

With $\mathbf{i_{ntotx1}}$ the summation vector. Then simplifying, is possible to define the Leontief inverse matrix $\mathbf{L_w}$.

$$\mathbf{x}_w = (\mathbf{I} - \mathbf{A}_w)^{-1} \cdot \overline{\mathbf{f}}_w, \qquad \mathbf{L}_w = (\mathbf{I} - \mathbf{A}_w)^{-1} \qquad (3.7)$$

With $\widehat{\mathbf{f_w}}$ the diagonalization of the column vector resulting of the summation process on $\mathbf{f_w}$**,** and with:

$$\mathbf{x}_W = \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^N \end{bmatrix}, \ \mathbf{A}_W = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} & \cdots & \mathbf{A}^{1N} \\ \mathbf{A}^{21} & \mathbf{A}^{22} & \cdots & \mathbf{A}^{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}^{N1} & \mathbf{A}^{N2} & \cdots & \mathbf{A}^{NN} \end{bmatrix} \qquad (3.8)$$

Vector $\mathbf{B_w}$ is defined as follows:

$$\mathbf{B}_W = \mathbf{R}_W \cdot \hat{\mathbf{x}}_w^{-1} \qquad (3.9)$$

With $\hat{\mathbf{x}}_\mathbf{w}$ the diagonalization of the column vector $\mathbf{x_w}$**.** Being row vector $\mathbf{B_W}$ (1xn_{tot}) the amount of energy directly required per dollar of production for each economic sector (ktoe/kUS$). This vector is called the world energy intensity. The vector of embodied energy consumption for each sector in the world, $\mathbf{E_W}$ (column vector (n_{tot}x1)) in ktoe, can be calculated with the previously defined matrices.

$$\mathbf{E}_W = \hat{\mathbf{f}}_W \cdot (\mathbf{B}_W \cdot \mathbf{L}_W)^T \qquad (3.10)$$

Column vector $\mathbf{E_w}$ contains the embodied energy consumption for each economic sector in the World (or in the multi-region framework). Through a simple process of aggregation based on this vector it is possible to build a vector containing the embodied energy consumption of each country or region. This is the most basic methodology for energy CBA using IO tables in a global framework. However, based on this methodology it is possible to develop or discuss some novel approaches that gives further information by decomposing or modifying mathematically the results of MRIO analysis.

3.2.2.1 Origin of Energy Embodied in Consumed Goods and Services

One of these novel approaches exposes the origin of energy embodied in goods and services consumed by each economy. In other words, this approach allows to know the origin of the primary energy (energy resources) used to sustain the production of the final demand for each country, i.e. to state from which economy such amount of energy resources is extracted. Consequently, for develop this methodology the proper energy vector to be used is built allocating the fossil fuel primary production to a proper sector (Mining & Quarrying in this work). And the results achieved are useful to analyze the energy dependency between countries considering international transactions of goods and services. This methodology, presented by Rocco et al in [75], present results form a demand side point of view, i.e. the results represent the embodied energy in the final demand of goods and services consumed by end-users in each country.

$$\overline{\mathbf{E}_W}\,(Nxn_{tot}) = \mathbf{f}_W^T \cdot [diag(\mathbf{B}_W)\cdot \mathbf{L}_W]^T \tag{3.11}$$

$$\overline{\mathbf{E}_W}\,(Nxn_{tot}) = \begin{bmatrix} f_{11} & \cdots & f_{1N} \\ \vdots & \ddots & \vdots \\ f_{n_{tot}x1} & \cdots & f_{n_{tot}xN} \end{bmatrix}^T \cdot \left[\begin{bmatrix} b_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & b_{n_{tot}} \end{bmatrix} \cdot \begin{bmatrix} l_{11} & \cdots & l_{1n_{tot}} \\ \vdots & \ddots & \vdots \\ l_{n_{tot}1} & \cdots & l_{n_{tot}n_{tot}} \end{bmatrix} \right]^T \tag{3.12}$$

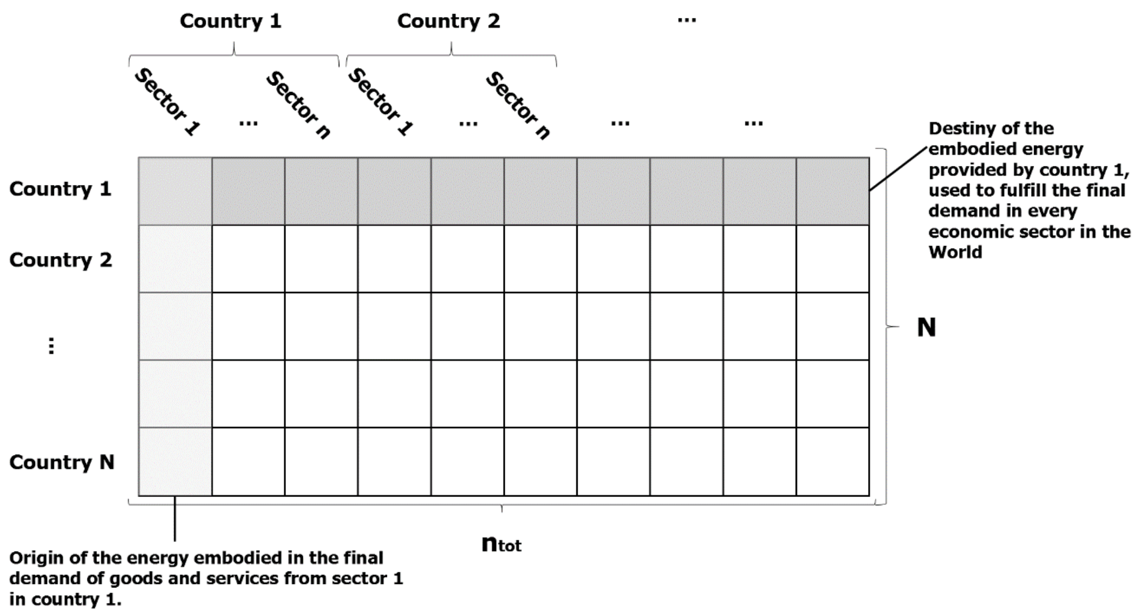

Figure 17. *Matrix* $\overline{\mathbf{E}_\mathbf{W}}$ *structure and physical meaning.*

The result of this paradigm is the matrix $\overline{\mathbf{E}_\mathbf{W}}$ with dimension *(N x* n_{tot}*)*, the *N* rows represent the origin of the energy, and the n_{tot} columns represent the final demand of each sector. Thus, column ***j*** represents the demand of sector ***j*** decomposed by the ***N*** countries from which the energy has been extracted. On the other hand, row ***i*** represents to which sectors and countries is providing energy country ***i***. The figure above shows the shape of matrix $\overline{\mathbf{E}_\mathbf{W}}$ and the definition of the rows and columns of such matrix. Since it is a CBA methodology, it is possible to analyze or highlight the energy relationships between countries, and since the energy vector used is reflecting the fossil fuel primary production, these results could be used for analyzing the energy dependency of countries in fossil fuel reserves of other countries. In the figure below, a circular diagram is showed that represents the matrix $\overline{\mathbf{E_W}}$ (for African countries) without the diagonal elements and, consequently, represents the fossil fuel dependency between the analyzed countries.

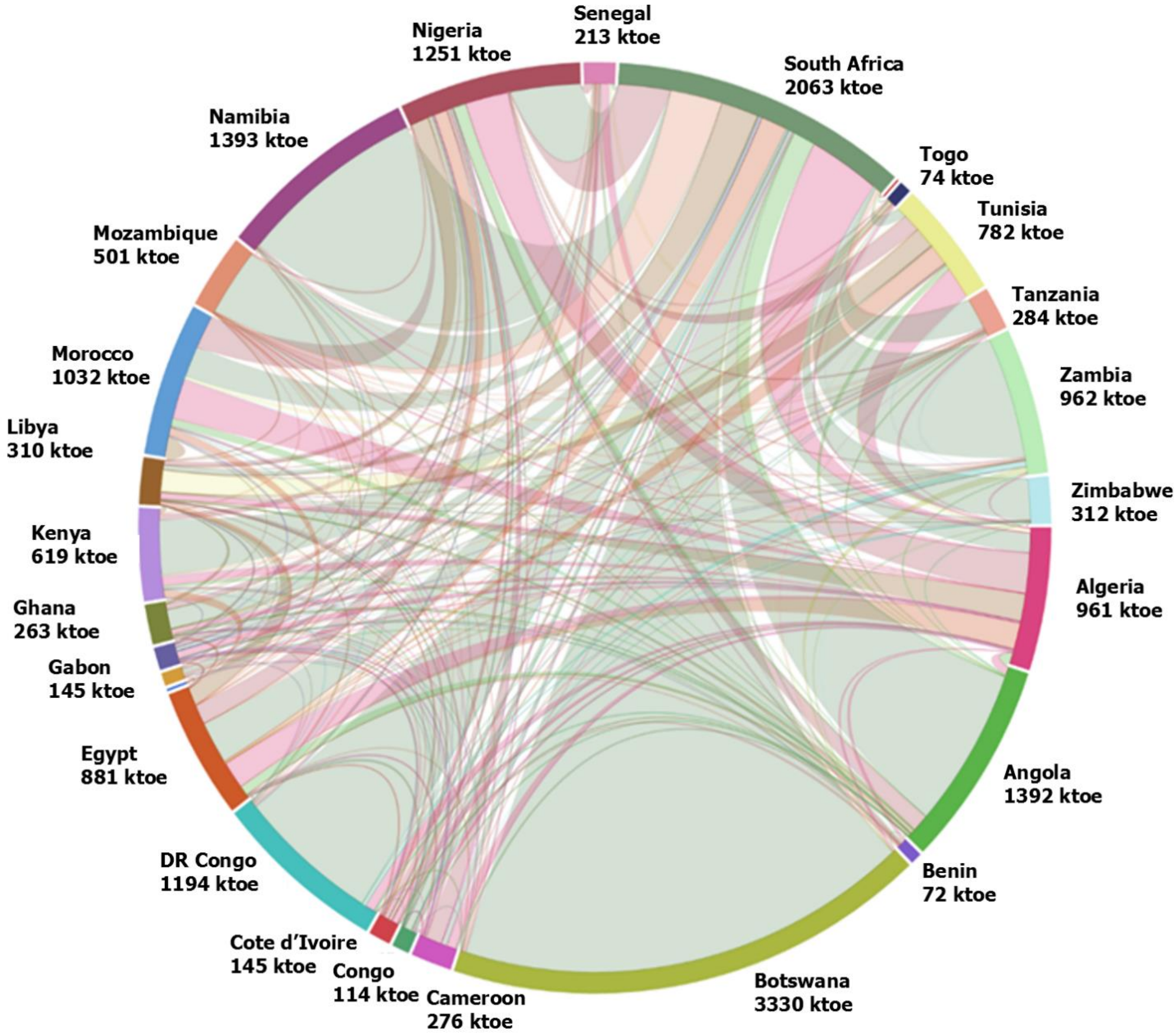

Figure 18. *Example of energy relationships between African countries extracted from matrix* $\overline{\mathbf{E_W}}$

The thickness of the links is proportional to the fossil fuel related energy received by each country. For example, the link between Botswana and South Africa is very thick in the side of Botswana, meaning that this country has a strong dependency on fossil fuels from South Africa. On the other hand, in the side of South Africa the link becomes very thin, what means that South Africa receive very few fossil fuel related energy from Botswana. In brackets, next to the names, the number indicates the total amount of fossil fuel related energy that each country receives from others.

3.2.2.2 Decomposition of Embodied Energy consumed by a productive sector

Another novel approach is derived from MRIO analysis in this section. This time, the result achieved allows to decompose or break-down the embodied energy invoked by each economic sector in order to fulfill its production. In other words, it is possible to know what economies and what economic sectors are supporting the production of the analyzed sector. A very similar approach has been recently proposed by Masahiro Sato et al in [67] for analyze energy dependencies between countries and set optimal energy portfolios. The results of this paradigm will provide information on how the economic sectors, in a domestic or international way, are related to each other in terms of energy. This will be especially relevant when analyzing economic sectors which have small direct energy requirements, but important indirect energy requirements, as usually happens with Construction or Public Administration, since it is possible to know which sectors (or which countries) are providing that indirect energy requirements. Mathematically, this approach can be defined as:

$$\mathbf{S}_W\,(n_{tot}\,x\;n_{tot}) = diag(\mathbf{B}_W)\cdot\mathbf{L}_W\cdot diag(\mathbf{f}_W\cdot\mathbf{i}) \tag{3.13}$$

$$\mathbf{S}_W\,(n_{tot}xn_{tot}) = \cdot\left[\begin{bmatrix} b_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & b_{n_{tot}} \end{bmatrix}\cdot\begin{bmatrix} l_{11} & \cdots & l_{1n_{tot}} \\ \vdots & \ddots & \vdots \\ l_{n_{tot}1} & \cdots & l_{n_{tot}n_{tot}} \end{bmatrix}\right]\cdot\begin{bmatrix} f_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & f_{n_{tot}} \end{bmatrix} \tag{3.14}$$

Since this paradigm analyzes the productive relationships between economic sectors, the proper energy vector to be used should be built by the TPES per sector. In that way, it is possible to see how the TPES per sector (i.e. the fossil fuel related energy burnt by each industry) is then re-distributed between all the economic sectors due to the intermediate transactions and productive interactions. Furthermore, these interactions are not restricted to economic sector but also happens between countries (actually between economic sectors in different countries). This fact allows researchers to classify countries and economic sectors as "energy burners" or "energy consumers", depending on their direct energy requirements and on the embodied energy invoked as inputs for their production processes. Figure X contains the shape and explanation of matrix $\mathbf{S_W}$**.** The rows represent the destiny of the energy burnt by each sector, and the columns represent the embodied energy inputs that receives each sector in order to be able to fulfill their production e.g. row ***i*** represents the energy burnt by sector ***i*** and where is it sent to support production processes, the summation of every element of row ***i*** is the TPES consumed by sector ***i***. On the other hand, column ***j*** represents the embodied energy inputs received by sector ***j*** from other sectors, the summation of every element of column ***j*** is the embodied energy consumption of sector ***j***. This approach is based on the proposal by Hong et al. in [76], in which a variation of structural path analysis (SPA) is used in order to achieve similar results by applying power expansion series to MRIO model. The substantial difference is the threshold value that needs to be set on Hong's approach, which at the end means a loss of information. The methodology proposed in this work is based on a novel definition of the Leontief's coefficients (elements of matrix $\mathbf{L_W}$). In fact, matrix $\mathbf{L_W}$ could be decomposed through power expansion series, and according to Suh et al, has the following property [77].

$$\mathbf{L}_W = (\mathbf{I}-\mathbf{A}_W)^{-1} = \mathbf{I}+\mathbf{A}+\mathbf{A}^2+\mathbf{A}^3+\mathbf{A}^4+\cdots+\mathbf{A}^N \tag{3.15}$$

$$\lim_{n \to \infty} \mathbf{A}^n = 0 \quad (3.16)$$

Consequently, the matrix $\mathbf{E_W}$ can be also decomposed as:

$$\mathbf{E}_W = \overbrace{\mathbf{B}_W \cdot \mathbf{I} \cdot \mathbf{f}_W}^{Stage 0} + \overbrace{\mathbf{B}_W \cdot \mathbf{A}_W \cdot \mathbf{f}_W}^{Stage 1} + \overbrace{\mathbf{B}_W \cdot \mathbf{A}_W^2 \cdot \mathbf{f}_W}^{Stage 2} + \overbrace{\mathbf{B}_W \cdot \mathbf{A}_W^3 \cdot \mathbf{f}_W}^{Stage 3} + \cdots + \overbrace{\mathbf{B}_W \cdot \mathbf{A}_W^N \cdot \mathbf{f}_W}^{Stage N} \quad (3.17)$$

And according to equation (3.16) each stage has a decreasing importance from an energy point of view. Thus, making a definition of Leontief's coefficients based on the power expansion series decomposition:

$$l_{ij} = i_{ij} + a_{ij} + \sum_{l=1}^{n} a_{il} \cdot a_{lj} + \cdots \quad (3.18)$$

The Leontief's coefficients l_{ij}, are traditionally defined as the amount of product from ***i*** required to fulfill a unit of final demand of ***j***. Under the previous terms, one new definition can be stablished for Leontief's coefficients: the aggregation of every specific path which begins in ***i*** and ends in ***j***. This novel definition is used to build the matrix $\mathbf{S_W}$ which elements are mathematically defined as:

$$\mathbf{S}_W \, (n_{tot} \, x \, n_{tot}) \;\; \rightarrow \;\; s_{ij} = b_i \cdot l_{ij} \cdot f_j \quad (3.19)$$

Elements of matrix $\mathbf{S_W}$ are, so, the aggregation of every energy path from ***i*** to ***j.*** In other words, s_{ij} coefficients are the embodied primary energy used or burnt in sector ***i*** that is used in the production of sector ***j***. So, the researchers are now able to make a decomposition of the embodied energy consumed by one sector in terms of sectors and/or regions as can be seen in figure 16. This figure shows the embodied energy consumption of Construction sector in Angola and how it is decomposed in terms of its origin from regions or sectors. In other words, it exposes which sectors and countries (or regions) support the production of Construction sector in Angola in terms of embodied energy.

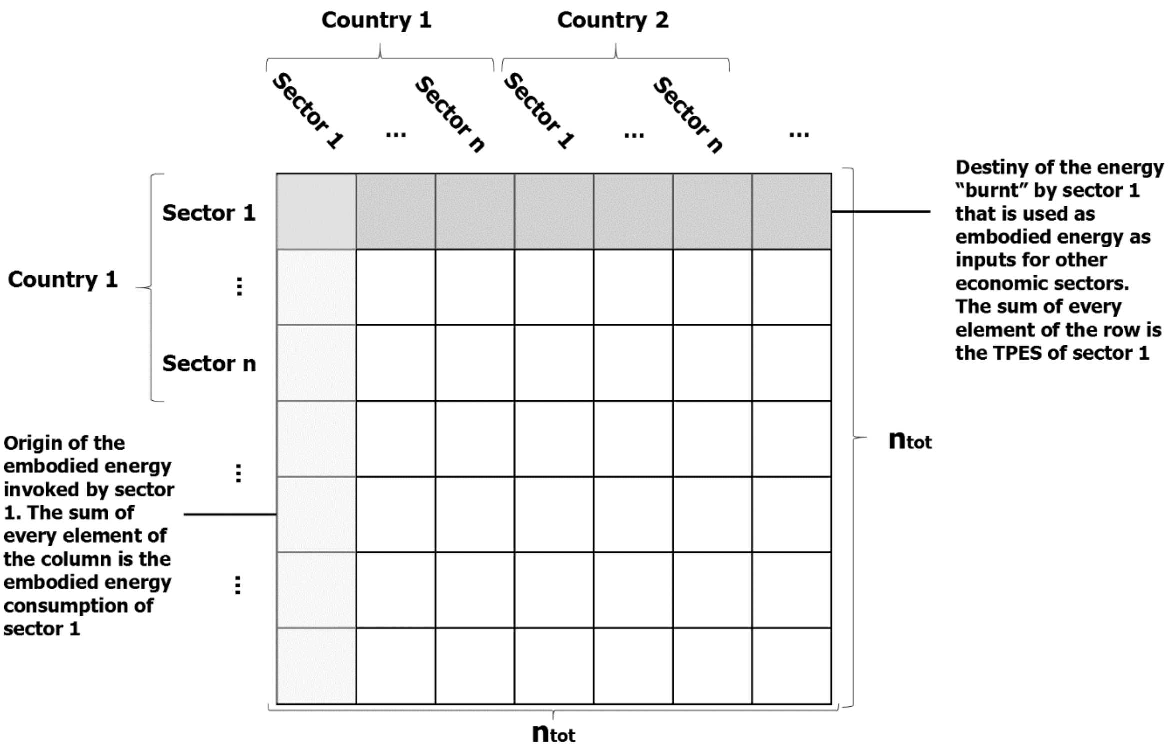

Figure 19. *Matrix* $\mathbf{S_W}$ *structure and physical meaning.*

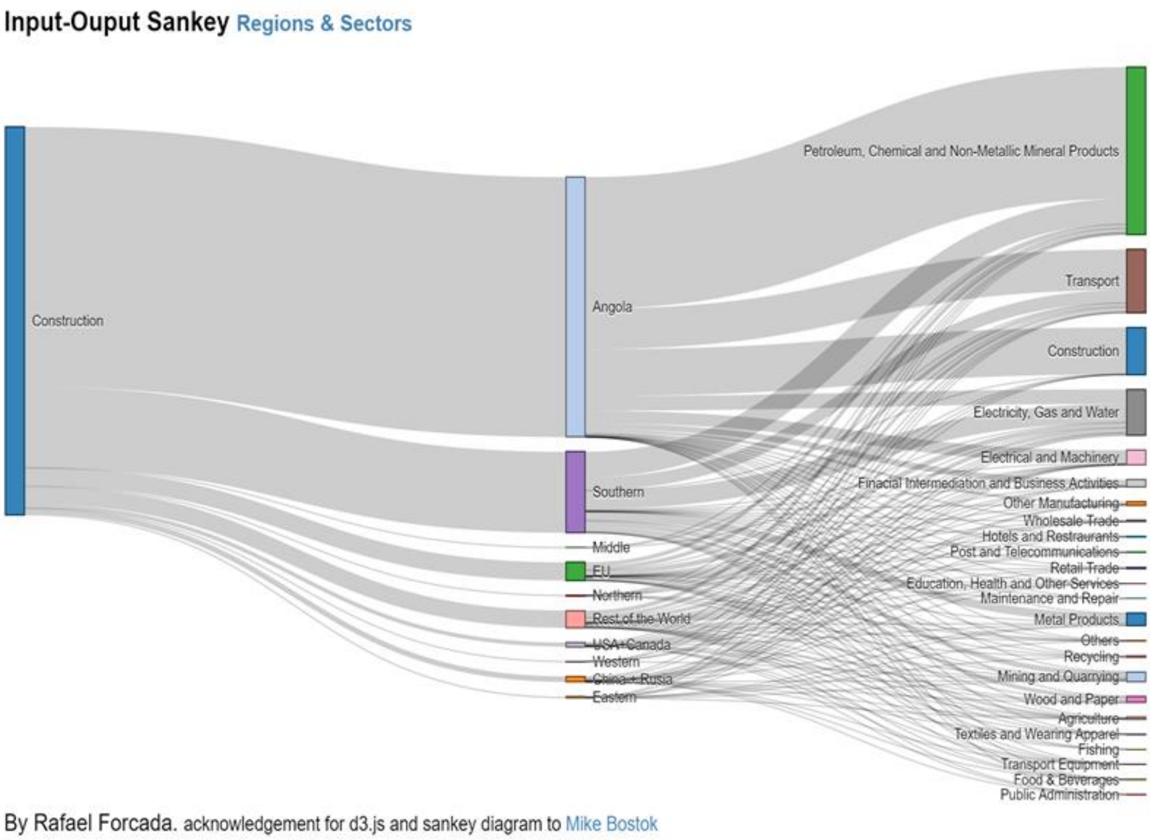

Figure 20. *Example of decomposition of the embodied energy consumption of a sector extracted from Matrix* $\mathbf{S_W}$*.*

3.2.2.3 Decomposition of Embodied Energy on final demand

This approach consists on a decomposition of the energy embodied in the final demand of goods and services consumed by each country. It does not reflect the origin of the embodied energy in final demand, but analyzes in terms of embodied energy the trades of goods and services between countries dedicated to satisfying final demand. This methodology is proposed by Rocco et al in [75] for analyze the final demand distribution of embodied energy. Modifying mathematically MRIO model, this new approach could be defined mathematically as:

$$\mathbf{D}_W\,(n_{tot}\,x\,N) = diag(\mathbf{B}_W \cdot \mathbf{L}_W)^T \cdot \mathbf{f}_{n_{tot}xN} \tag{3.20}$$

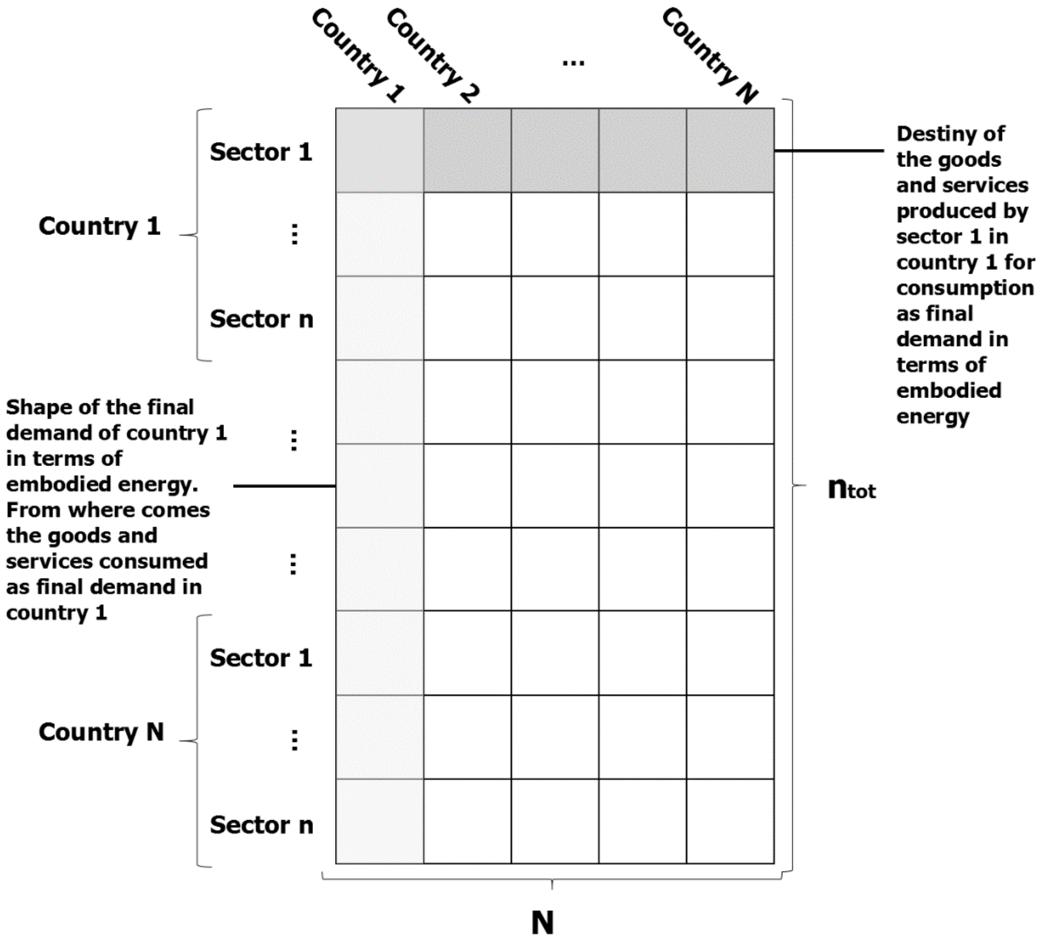

Figure 21. *Matrix* $\mathbf{D_W}$ *structure and physical meaning.*

The result is matrix $\mathbf{D_W}$ with dimension ($n_{tot}\,x\,N$), its rows represent each one of the economic sectors in the global economy, and its columns represent the N countries or regions in the model. Column ***j*** of the matrix represent the shape of the final demand of country ***j***, so the origin of the goods and services consumed as final demand in that country are exposed in terms of embodied energy. Row ***i*** contains the embodied energy in production of sector ***i*** and how it is distributed among the analyzed countries in order to be consumed as final demand.

3.3 Supply and demand sides on CBA and PBA

Both energy accounting methodologies represent different segments of the energy chain. And in both segments, could be distinguished a supply and demand side. In this section, the separation between supply and demand side in both energy accounting methodologies is stated and explained. This supply/demand paradigm will be crucial for achieve a joint use of CBA and PBA, and also to identify the proper policies and the proper area of the energy chain in which intervene to maximize benefits from energy efficiency investments. This paradigm is based and focused on fossil fuel energy resources, therefore electricity is kept out from the TPES accounting, and it is quantified on the CBA side, represented by the sector Electricity, Gas & Water.

3.3.1 Supply and demand on PBA.

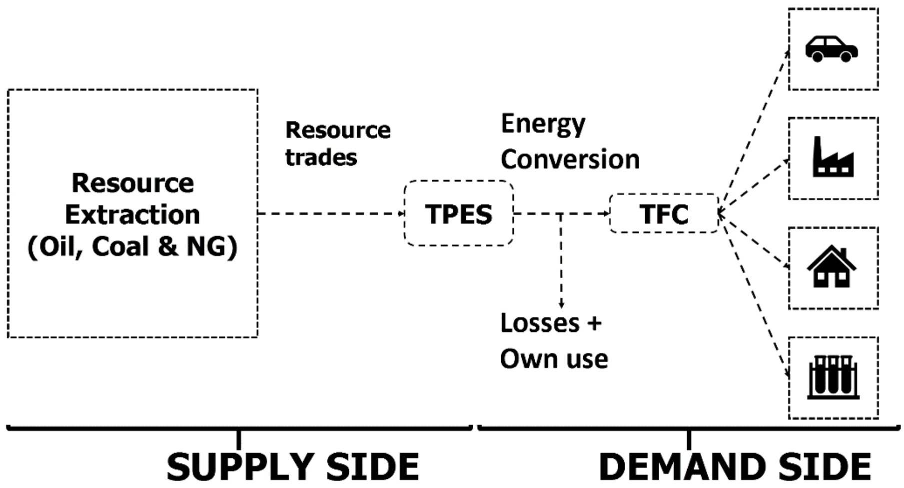

Figure 22. *Supply and Demand sides in PBA*

Production based accounting of fossil fuel related energy begins by reflecting the primary production of oil, coal and natural gas. Then a step of resource trading is identified: Countries, by means of public or private companies, import and export raw resources. In this way is calculated the TPES, which states for the requirement of fossil fuel resources of each country in order to provide energy to industries and households (Primary energy). Thereafter, a series of energy conversion processes take place, which involve a discount on the energy accounting in the shape of energy losses and industry own use. After the energy conversion processes, it is possible to speak about secondary energy (gasoline, diesel, electricity, heat…). Then, this secondary energy is used as an input for the main productive sectors (Transport, Industry, Residential, Commercial and public services, Agriculture/forestry, Fishing or Non-Energy use) as TFC, according to IEA standards. It is possible to see this countries and companies providing the extracted energy resource to other countries, and the conversion processes as a first supply of energy, or define it as the supply side of the PBA.

On the other hand, it is possible to state the definition of this sectors asking for energy inputs as the demand side of the PBA approach.

3.3.2 Supply and demand side on CBA

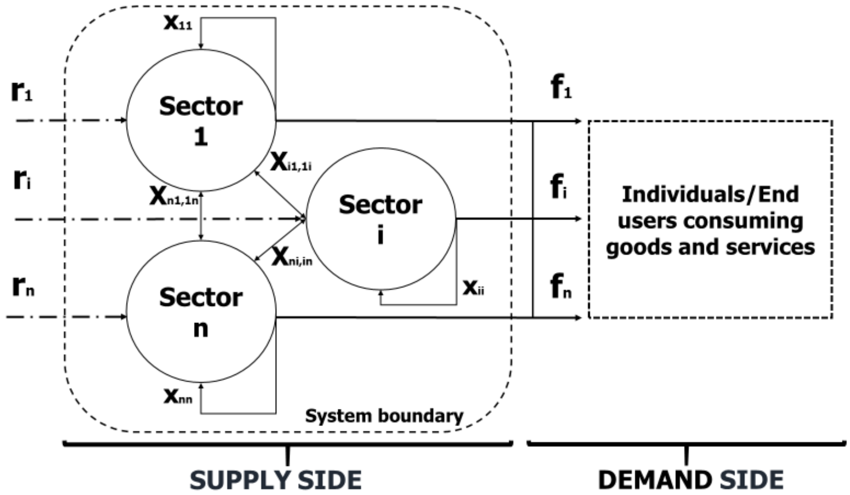

Figure 23. *Supply and Demand sides in CBA*

In the CBA approach, we have as input of the model an exogenous resource vector which represents the direct energy requirements of economic sectors, then is reflected the intermediate transactions among such economic sectors which implies a re-distribution of the energy inputs according to the real consumption of energy or embodied energy by the different industries. Here is identified another step of energy trading, in this case, embodied energy in the goods and services traded to sustain the different production processes. Thereafter these economic sectors serve the final demand to end-consumers, however this final demand is not served only domestically, but sectors in one country can supply their production to end-consumers in other countries. Consequently, another step of energy trading is identified, in this case the energy embodied in goods and services imported or exported by different countries and used to meet the final demand of end-consumers. The CBA supply side can be identified as the different economic sectors producing and providing embodied energy in goods and services, and the demand side as the end-users or consumers asking for the embodied energy in goods and services. However, these definitions are more difficult to state from a mathematical point of view, it is necessary to use two of the paradigms discussed before. By means of equations (3.13) and (3.14), the supply side of the CBA can be modeled. The resulting matrix, gives light of the endogenous inputs, in terms of embodied energy that receives each productive sector for be able to fulfill its production of goods and services. And using equation (3.20), it is possible to build a matrix that models the demand side on CBA, highlighting the shape of the demand in terms of embodied energy. By using the division in supply and demand sides of both methodologies of energy accountings, will be possible to use it in a combined way, taking profit of the advantages and useful information given by both of them.

3.4 Joint use of PBA and CBA: The whole Energy metabolism paradigm

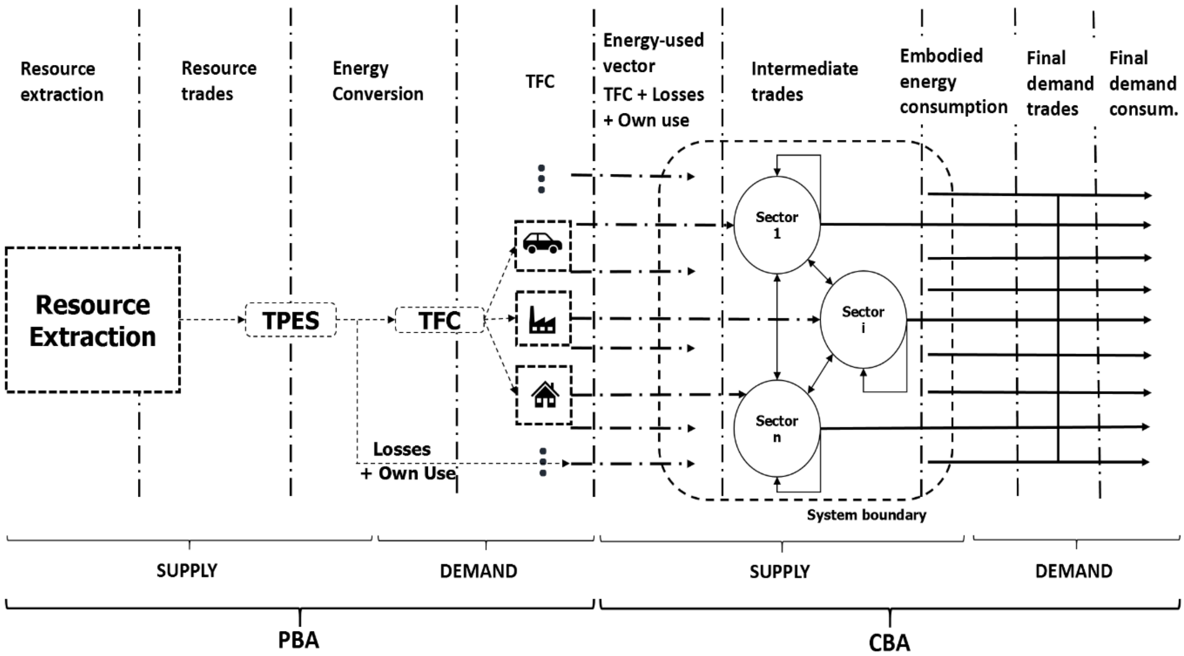

Figure 24. *Full energy metabolism. Joint use of PBA and CBA.*

Both accounting paradigms can be coupled to achieve a joint use with the aim of exploit the goodness of both methodologies. The key point for do this is the exogenous resource energy vector used for the CBA calculations. Exists two possible energy vectors that could be used for jointing PBA and CBA. First, an energy vector containing the TFC per sector, in other words secondary energy. Two main problems arise from this possibility: the accounting of electricity and heat, that need to be done before the CBA side; and the accounting of conversion losses and industry own use, that cannot be embodied in goods and services productions. Solving these two issues and using proper IO tables a joint use of PBA and CBA is achievable. On the other hand, if sectorial TPES is used as energy vector the two issues exposed before can be solved easily. Secondary energy as electricity and heat is reflected on CBA tables and allocated to proper sectors (e.g. Electricity, Gas & Water; in this work). In this case, it is not necessary to account for the energy conversion losses and the industry own used energy since we are using TPES as the input for the CBA calculations, and losses and industry own use will be "embedded" in goods and services as direct energy requirements by the industries. Thus, from the resource extraction we can find countries and companies trading energy resources and then "supplying" energy to the different economic sectors, in other words, the economic sectors are "demanding" their direct energy requirements. Up to this point the energy accounted have the shape of raw energy resources, and from here the energy accounted is embodied energy in goods and services. Thereafter, the economic sectors use such energy inputs to produce goods and services and gives place to the intermediate transaction step necessary for the different productive processes. Finally, this goods and services are consumed as final demand. We can identify the productive activities of economic sectors as the supply side of goods and services, and the end-users as the demand side for goods and services (and consequently for the embodied energy in them).

Nevertheless, a disadvantage of applying such methodology is the large amount of information that could not be showed properly, so the result presentation becomes a problem. This fact introduces the need of apply a certain degree of aggregation losing accuracy and insight in the assessment. Aggregation could be achieved in two different dimensions: a geographical one (i.e. aggregate countries into bigger regions, even continents. For example, Algeria would belong to Northern Africa and Northern Africa would belong to Africa in a higher level of aggregation). And economic (i.e. aggregate economic sectors into a wider classification, for example ISIC sector "Electrical equipment" and "Machinery and equipment" form "Electrical & Machinery" in EORA database, and both would belong to "Industry" in a superior aggregation level). The higher the level of result aggregation, the easier the result presentation but the lower level of detail and insight of the information represented. Therefore, the Energy Maps are presented as a sort of solution to this problem. The Energy Maps consists on a series of diagrams that represent the energy relationships among countries and economic sectors from different levels of aggregation and showing joint results of PBA and CBA. In the following sections the more remarkable Energy Maps are presented and explained.

3.4.1 Global Energy Map

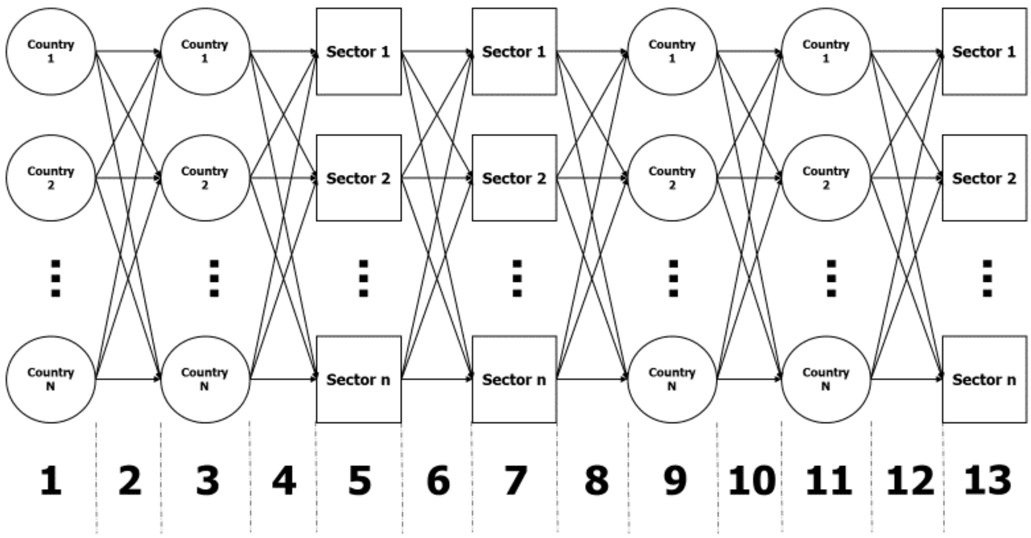

Figure 25. *Global Energy Map scheme.*

The highest level of aggregation. It contains the information related to all the countries and all the sectors, the transactions of energy resources between countries; the intermediate transactions in the production step; and the transactions of goods and services for satisfy final demand. This map is built using every vector of the paradigm, and consequently, the information contained on it is complete. The map could be represented as a nodal network in which both the nodes and the links between the nodes give valuable information for policy-makers. It would have a shape like the one showed in the figure above. And it can be explained in the following way:

1. Nodes representing the energy (fossil fuels) extracted within each country borders, primary energy production according to IEA standards.
2. Links representing the transactions (imports/exports) of fossil fuel resources between countries.
3. Nodes representing TPES per country.

4. Links representing TPES per sector in each country.
5. Nodes representing TPES dedicated to each sector at global level
6. Links representing the re-distribution of energy consumption in economic sectors through the intermediate transactions between productive sectors. This is the transition from PBA to CBA.
7. Nodes representing the embodied energy consumption per sector at global level.
8. Links representing the embodied energy consumption in production processes per sector in each country.
9. Nodes representing the embodied energy consumption in production per country.
10. Links representing the embodied energy in transactions of goods and services to satisfy final demand.
11. Nodes representing the embodied energy consumed as final demand of goods and services per country.
12. Links representing the embodied energy consumed as final demand of goods and services per sector in each country.
13. Nodes representing the embodied energy consumed as final demand of goods and services per sector at global level.

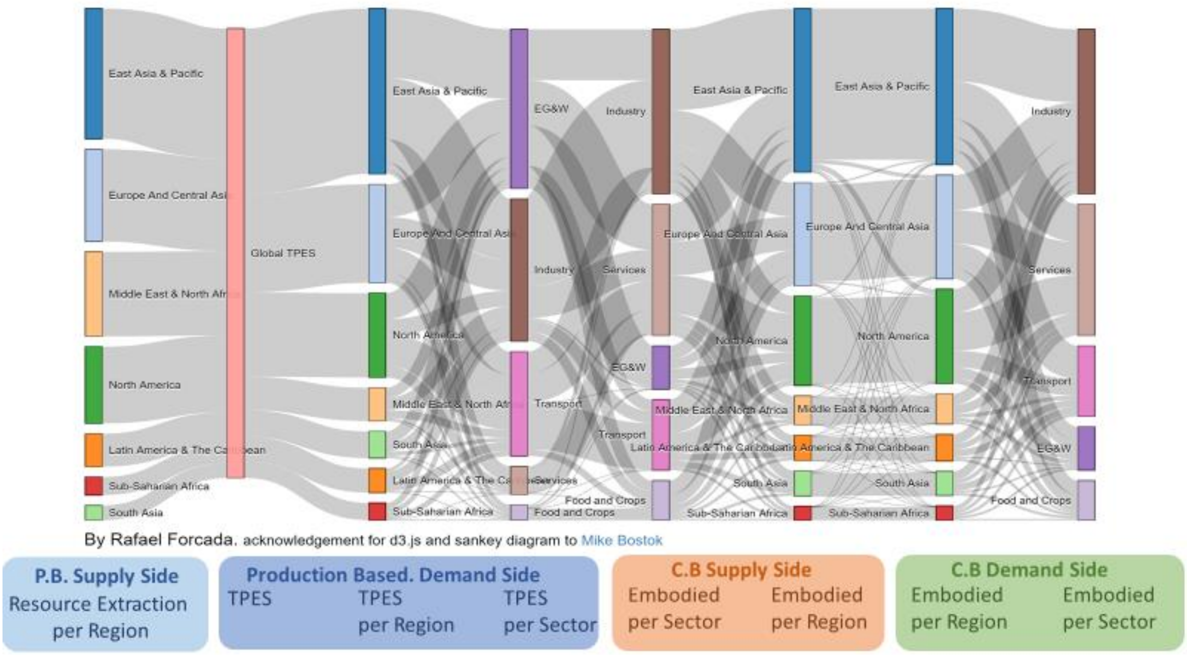

Figure 26. *Example of global energy map*

However, due to the large amount of information, the level of aggregation to achieve to be able to represent the global map in a graph is a drawback, as could be seen in the figure above. It is necessary to aggregate the countries into regions or continents; and reduce the number of sectors also. This will mean a loss of insight, and some valuable information will remain hidden under the aggregation. To give a solution to this drawback, lower level maps are proposed, trying to reflect the information missed in the global level due to aggregation issue.

3.4.2 Country Energy Map

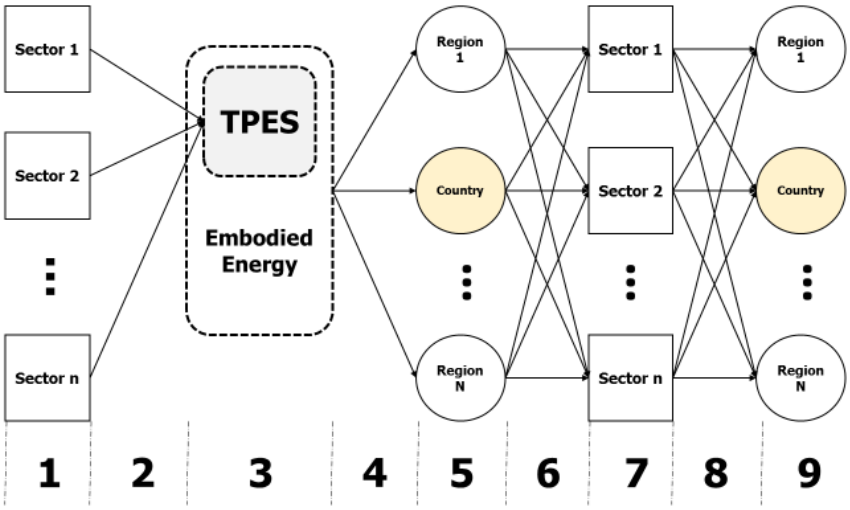

Figure 27. *National Energy Map scheme.*

Proceeding in a similar way, it is possible to focus the map on a specific country. It is still needed a certain level of aggregation, but since now the main target is to spotlight the energy metabolism of a single country (which obviously is not included in the aggregation) the problem of the geographical aggregation is avoided. This map is built using the vectors and the rows/columns of the matrix related to the selected country. The key point is to re-arrange the aggregation for give importance to the selected country or region. This map will highlight the energy metabolism of the selected country and its relationships with other countries or regions. In that way, the selected country (yellow on the explicative figure above) and its relationship with other regions are highlighted in the map. Another interesting advantage, is that this kind of map allows the researchers to give light on the difference between PBA and CBA, giving an idea about the importance of use the proper energy accounting method. The map is explained as follows:

1. Nodes representing the TPES (TFC + Losses + Own use) per sector in the analyzed country.
2. Links representing the sum of nodes 1, i.e. the TPES of the country.
3. Node representing the difference between the TPES of the country and the embodied energy consumed by productive processes within the country. This difference represents the second-degree energy dependency.
4. Links representing the country (or region) of origin of the embodied energy in goods and services produced in the selected country.
5. Nodes representing the economies supporting the production in the selected countries in terms of embodied energy.
6. Links representing the contribution of each country or region to each economic sector of the selected country.
7. Nodes representing the embodied energy consumption of each economic sector of the selected country for produce goods and services.

8. Links representing the place where the goods and services produced by each economic sector in the selected country are sent in order to be consumed as final demand, in terms of embodied energy.
9. Nodes representing the countries or economies that consume the goods and services produced in the selected country in terms of embodied energy. These nodes give light of third-degree energy dependency of other countries with respect to the analyzed country.

Note that, according to the statements made previously, it would be possible to represent more information regarding the PBA (i.e. the resource extraction and the resource imports and exports) however, the origin and destination of resources imported and exported is unknown (in the available data for this work), so, for sake of simplicity, since no new and useful information will be provided, that is not included in the map.

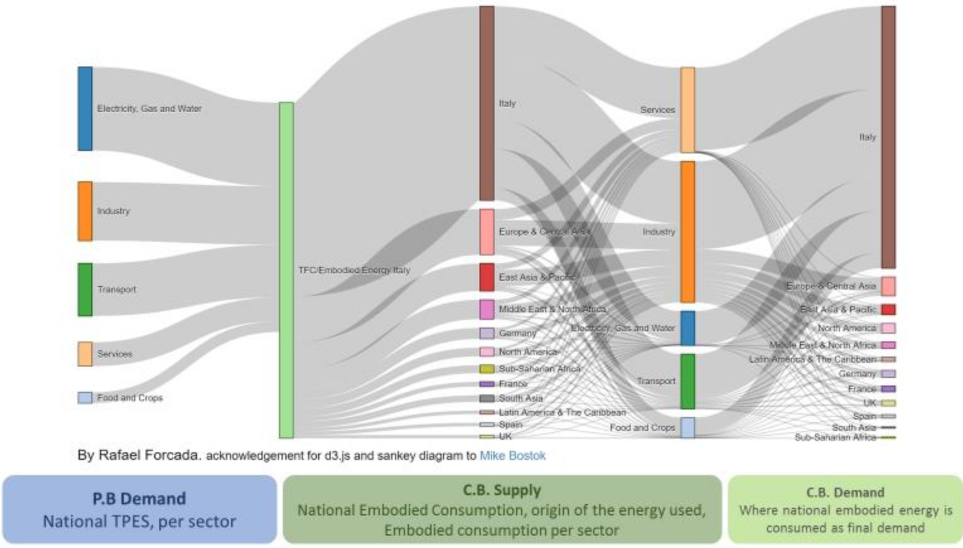

Figure 28. *Example of National Energy Map*

3.4.3 National Sector Map

Now, the target is to go deeper in the map representation, and to focus in a single economic sector of a certain economy. In this case, the aggregation of economic sectors is reduced to the minimum possible in order to be able to extract the more accurate information under these terms. In this occasion, the map is built by means of the vectors and rows/columns of the matrix corresponding to the country (or region) where belongs the selected country, and the rows and columns corresponding to the analyzed sector. This map will highlight the energy metabolism related to the selected economic sector, and its relationships with other sectors and countries.

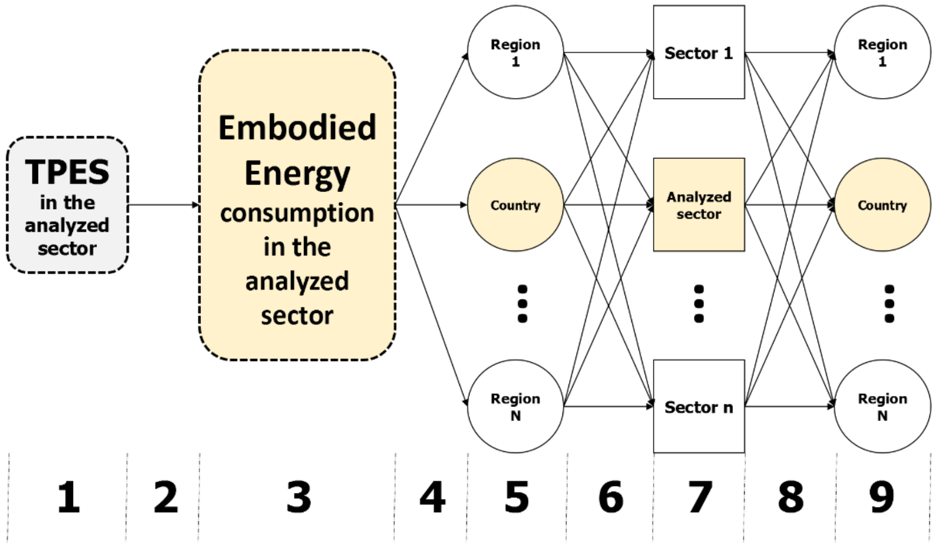

Figure 29. *National Sector Energy Map.*

The map can be explained in the following way:

1. Node representing the TPES (TFC + Losses + Own use) in the analyzed sector.
2. Link representing the difference between the TPES in the analyzed sector and the embodied energy consumption in its production of goods and services. This difference between analyze the sector using PBA and CBA.
3. Node representing the embodied energy consumption of the analyzed sector.
4. (and 5) Links and nodes representing the geographical origin of the embodied energy consumed by the selected sector in its productive activities. These represent the second-degree energy dependency of the country to which the analyzed sector belongs, related to the selected sector.
6. Links representing the amount of embodied energy provided by each sector of each economy to the analyzed sector production.
7. Nodes representing the global contribution of each sector to the production process of the selected sector, in terms of embodied energy.
8. Auxiliary node, it does not give useful information.
9. Countries or economies in which the goods and services produced by the analyzed sector are consumed, in terms of embodied energy. These nodes represent the third-degree energy dependency (related to the selected sector) of other countries with respect to the country to which the sector analyzed belongs.

Again, there is a lack of information in the map, regarding to PBA, concretely related to the resource extraction and the first-degree energy dependency. And, as before, this is due to a lack of data involving the origin or destiny of imports/exports of resources extracted. This time both in terms of countries and sectors.

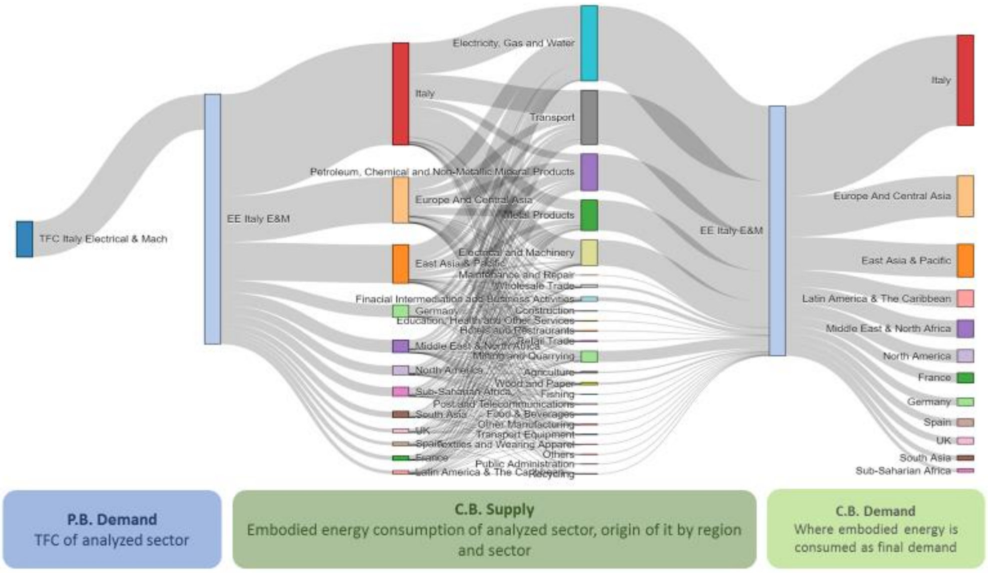

Figure 30. *Example of National Sector Energy Map.*

3.5 Energy trades and energy dependency degrees

As can be easily seen, the energy metabolism exposed as a result of a joint use of PBA and CBA is formed by several steps very differentiated between them (Figure 20). These steps can be used for identifying and classifying three kind of energy trading between countries. Furthermore, these different kinds of trade are closely related with the three types of energy improvement defined at the beginning of this work, and it can be used for stating a new definition and classification of energy dependency, which will be very useful when speaking about energy security and geopolitical issues. The first one, is related with raw energy resources trade, it can be identified in the first steps of the energy metabolism. After the primary production of energy (which states for raw resources as coal, natural gas or oil), countries stablish a first trade of energy through the import/export of this kind of material resources, which finally gives shape to the TPES. It is possible to speak about a first-degree of energy dependency when a country relies on the energy resources exported by other. This is the conventional energy dependency, and its mathematical definition is:

$$1^{st} \text{ degree of energy dependency} = \frac{TPES}{Imports} \tag{3.21}$$

This first step of trade and energy dependency is related to the energy improvement named Resource change, which consists in substitute a fossil fuel with a renewable source (i.e. instead of producing a certain amount of electricity with a coal power plant, produce it with a photovoltaic or hydroelectric plant). It can be stated that it will be always better to shift to a renewable source from a foreign fossil fuel than from a domestic fossil fuel. The second one is related with the intermediate trade between economic sectors (domestically and externally) made in order to have the necessary inputs to fulfil production. In order to produce their characteristic goods and services, economic sectors need the input of the production from other sectors; these inputs have energy embodied in them. So, consequently, a new degree of energy dependency is stablished in this step of trading, since economic sectors of one country could be relying on embodied energy coming from another country through the intermediate inputs. This is the definition of the second-degree of energy dependency, and its mathematical statement:

$$2^{nd} \text{ degree of energy dependency} = \frac{EE\ Consumed\ by\ national\ economic\ sectors}{EE\ provided\ by\ other\ countries\ to\ national\ economic\ sectors} \tag{3.22}$$

This information can be extracted from the columns of matrix $\mathbf{S_W}$. And it is related to the energy improvement in energy efficiency in economic sectors, when it is understood as providing the same output using less inputs. When the reduction of the inputs means a reduction of inputs coming from abroad, the improvement will be accompanied by a reduction in the second-degree energy dependency. A country depending in a second degree way on another country, depends indirectly on the countries on which the second country depends in a first degree. (i.e. Country A depends in a second degree on country B, and country B depends in a first degree on country C; if a situation of country C interrupts the first-degree trades between C and B, A could be indirectly affected).

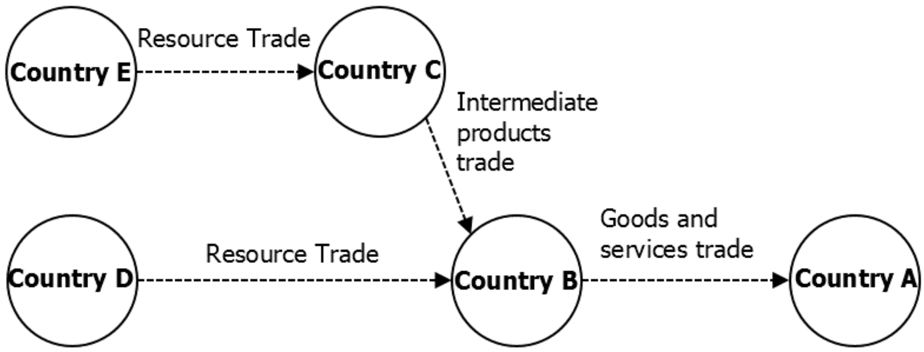

Figure 31. *Example: Country A has a third-degree dependency with respect to Country B, but it could be affected by changes in energy systems of countries C, D and E, indirectly*

The third step of trade is related to the trade of goods and services between different countries, dedicated to meet final demand of end-consumers. In fact, these goods and services have energy embodied on them, so, consequently, by this trading countries are acquiring a new kind of energy dependency with others. That is closely related with the energy improvement known as Energy savings (i.e. a reduction on final demand means a reduction in energy consumption). This information could be extracted from the columns of matrix $\mathbf{D_W}$. This is defined as the third-degree of energy dependency, again, a country having a third degree of energy dependency with another, could be affected indirectly by changes in other countries on which the second country depends (i.e. if country A has a third-degree energy dependency on country B, and country B depends in a second-degree on country C and in a first-degree on country D, and country C depends in a first-degree on country E; any situation that modifies the energy metabolism or trades in countries B, C, D and E; could affect, indirectly, to country A (see figure above)). the mathematical expression of the third-degree energy dependency is:

$$3^{rd}\ \text{degree of energy dependency} = \frac{EE\ Consumed\ by\ national\ \ final\ demand}{EE\ \ provided\ by\ other\ countries\ to\ \ final\ demand} \tag{3.23}$$

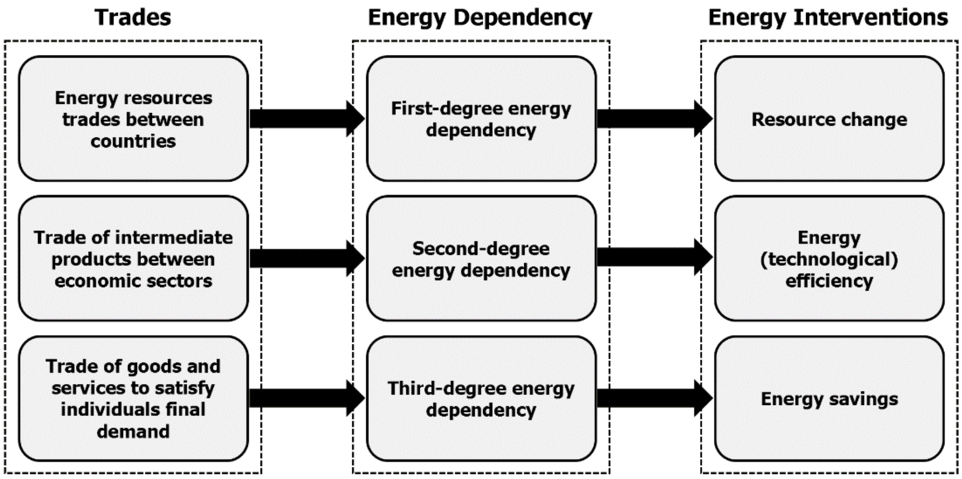

Figure 32. *Relationship between energy trading steps, different degrees of energy dependency and different kind of energy interventions.*

3.6 Energy Metabolism analysis: Steps and Application guidelines

In this section, a summary of all the approaches stated by now is done. The main equations, the result matrices, and the information that could be extracted from each one is presented in a single table. It is also showed the proper way to present results in order to make consultation easier to policy-makers. Finally, a guideline is presented which main target is give light on the procedure of make an energy analysis able to represent the whole energy metabolism of a certain country or region in several levels and capable of identifying bottle-necks or large energy flows, and give information on the proper way to intervene on it when looking for energy efficiency or energy savings.

3.6.1 Approaches summary (CBA)

In the table below, the paradigms described before are summarized, representing the main equations, the information provided and their usefulness in the energy analysis.

Paradigm	*Equation*	*Information*	*Usefulness*
Conventional MRIO	$\mathbf{E}_W\,(n_{tot}\,x\,n_{tot}) = diag(\mathbf{f}_W)\cdot(\mathbf{B}_W\cdot\mathbf{L}_W)^{T*}$	Embodied energy consumption per economic sector in each country	Ranking of economic sectors, and/or countries (regions) in terms of energy consumption according to CBA
Origin of energy embodied in consumed goods and services	$\overline{\mathbf{E}_W}\,(N\ x\ n_{tot}) = \mathbf{f}_W^T\cdot[diag(\mathbf{B}_W)\cdot\mathbf{L}_W]^T$	Origin of extracted (or burnt) energy embodied in goods and services consumed as final demand in each country	First-degree or Second-degree (depending on the energy vector used in calculations) energy dependency between countries according to CBA
Decomposition of embodied energy consumed by a productive sector	$\mathbf{S}_W\,(n_{tot}\,x\,n_{tot}) = diag(\mathbf{B}_W)\cdot\mathbf{L}_W\cdot diag(\mathbf{f}_W)$	Origin of the embodied energy used by economic sectors in production processes. Economies and sectors supporting production.	Second-degree energy dependency from supply-side p.o.v. Relationships between economies and sectors in terms of embodied energy according to CBA. Energy maps.
Decomposition of embodied energy on final demand	$\mathbf{D}_W\,(n_{tot}\,x\,N) = diag(\mathbf{B}_W\cdot\mathbf{L}_W)^T\cdot\mathbf{f}_{n_{tot}xN}$	In which country the embodied energy in goods and services produced by a sector (or a region) is consumed as final demand	Third-degree energy dependency. Embodied energy consumed by individuals according to CBA. Energy maps.

Table 2. *CBA Paradigms Summary*

3.6.2 Methodology guideline

In this section, an instruction script is presented, in order to use properly all the paradigms and theory previously explained, for build a solid and deep energy analysis tool, capable to designate specific economic sectors, countries, action areas and stakeholders, in terms of priority for energy interventions, and relate it with specific recommendations extracted from specialized literature. Of course, then, these results must be put in context by policy-makers, regarding political issues, technologic constraints, available budget, and other possible priorities.

1. Set territorial and time boundaries for the analysis. Time boundary recommended is 1 year, since most of the databases available are organized in that time frame. Depending on the number of countries, set the different geographical levels for the analysis (Global, continental, regional, national, etc.)

2. The benchmarking process: Identify and state the main stakeholders and action areas related to energy policies and energy actions towards energy efficiency and energy savings. Set it in a rational way and contextualizing with the scope of the analysis. Through research on literature build a conceptual matrix relating each pair of stakeholder-action area with specific recommendations/policies/actions/interventions found in literature. With this matrix, it is possible to highlight which are the main stakeholders and the most important action areas, based on the observation on the attention that literature pays to each of them. It is possible also to have an initial idea about the proper direction that an energy strategy must follow.

3. Prepare a preliminary analysis using both PBA and CBA (conventional MRIO). Stablish a ranking of regions (countries) in terms of primary production, TPES, and embodied energy consumption. It's important to make it from a higher to a lower level of aggregation (i.e. global, continental, multinational regions, national, etc.). Using results of conventional MRIO and TPES by sector, make, also, a ranking of economic sectors attending to its TPES and its embodied energy consumption. This preliminary analysis gives a preliminary information in terms of the three degrees of energy dependency of each territory, and also about the difference of the accounting methods, which represent different steps of the energy chain. With these results, most consumer sectors and countries (regions) are set as targets.

4. Apply the paradigm of the *Origin of energy embodied in consumed goods and services* using an energy vector of primary production (energy resources extracted within the country boundaries), this sub-analysis is useful to have an idea about the first-degree energy dependency between the analyzed countries, despite it is made from a CBA point of view. This is especially useful, due to the lack of data regarding to resource transactions between the countries (i.e. it's possible to know how much resources imports/exports certain country, but it's not possible to know to or from where it comes). With matrix $\overline{\mathbf{E_W}}$ is possible to build a circular diagram highlighting the energy dependencies between the analyzed countries. This is very important, since the coordination and cooperation between countries is crucial in order to achieve success, and energy dependency through geopolitical issues will be a crucial issue regarding international cooperation.

5. Once the country or region has been targeted, by matrices $\mathbf{D_W}$ and $\mathbf{S_W}$ built with the paradigms of *Decomposition of embodied energy consumed by a productive sector*, and *Decomposition of embodied energy on final demand*, the energy metabolism map of the specific country or region is drawn. This map can be analyzed in order to spot and understand the differences between CBA and PBA, the energy "burnt" locally per support the productive activities of economic sectors, and the energy used actually by economic sectors in order to fulfill the final demand of their products. The map also highlights the second-degree dependency of the country sector by sector, and the third-degree energy dependency of other countries with respect to him. Depending on the information of the map, more countries could be set as sub-target.

6. By using the ranking of sectors, and the information highlighted in the national (regional) maps, sectors are analyzed under the same terms. Representing the energy chain, from sectorial TPES to the final demand of goods and services. In that, way is possible to highlight the bigger energy flows between different sectors (I the same country or no), by means of representing relationships between economic sectors in terms of embodied energy. In other words, by knowing the energy relationships between economic sectors, researchers should be able to identify on which sectors focus efforts (or investments) in order to reach the maximum benefit, and also to identify the sectors which will be indirectly benefited by that efforts.

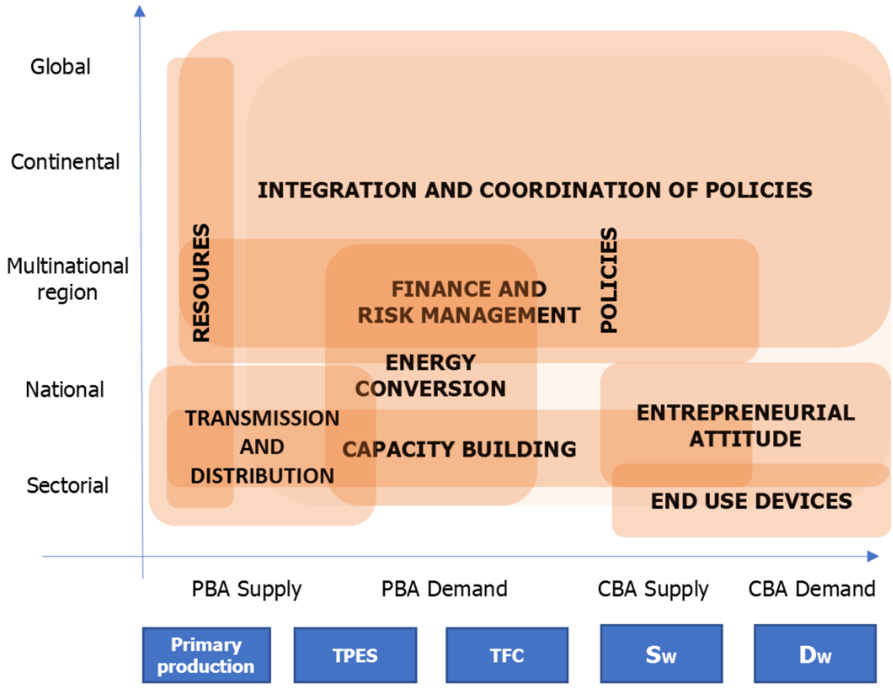

Figure 33. *Coupling analysis with Action areas*

7. The results of the analysis can be coupled with the benchmarking matrix, (figures 29 and 30) relating action areas and stakeholders with the several aggregation levels of the analysis and the different phases on the energy chain. In that way, it is possible to target one or more specific economic sectors, from one or more countries or regions; select the phase or phases of the energy chain in which intervene, and identify corresponding action areas and stakeholders. And finally, extract from the matrix some recommendations that allows to begin to design an energy strategy.

8. This process is iterative. Once the first sector(s), country (-ies) targeted have been analyzed, continue with the same methodology by targeting a new sector/country using the energy rankings. In that way, once the main energy intensive sectors of the economies analyzed have undergone this process, a first approach to a solid energy strategy towards energy efficiency and energy savings, had been stated; based on benchmarking and a deep energy analysis by using PBA and CBA.

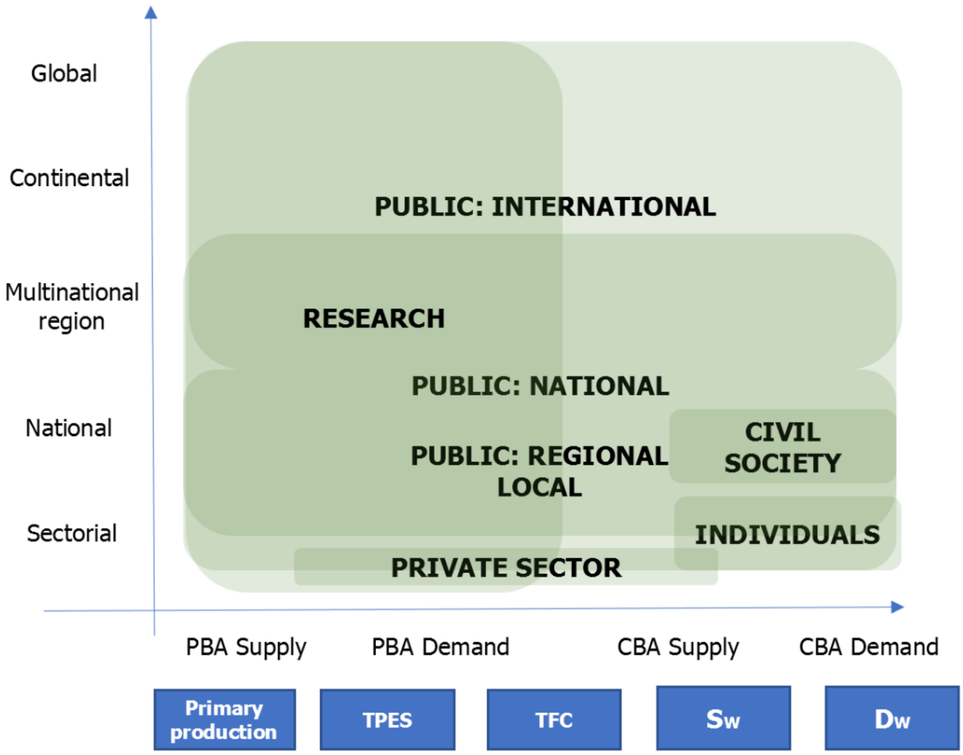

Figure 34. *Coupling analysis with Stakeholders*

The following flow diagram explains the energy analysis algorithm. Must be noticed that this is not a rigid and automatic process, and the knowledge and rational behavior of the researcher is essential for achieve successful results. The researcher must be capable to extract solid conclusions from the analysis in order to fulfill successfully each step of the iterative process, identifying the different dependencies among countries and economic sectors, and recognizing when other sectors or other countries will be benefited with an intervention on a specific sector, and when help form other sectors and countries is required in order to improve energy efficiency or achieve energy savings. These aspects are crucial for enhance international cooperation and coordination. The researcher must be also capable to identify by analyzing the energy maps in which part or parts of the energy chain is better to act in order to maximize the decrease of fossil fuel consumption (i.e. decrease the direct resource requirement, increase energy efficiency by producing the same output using less input, decrease indirect energy requirement, decrease consumption of energy by decrease final demand, etc.). In the diagram, the blue nodes represent processes related to the benchmarking matrix (stakeholder and action areas identification), and the yellow nodes represent processes related to the energy assessment. Continuous line arrows represent the transition from the different steps or processes in the algorithm, and discontinuous line arrows represent the necessary information fluxes between the different processes.

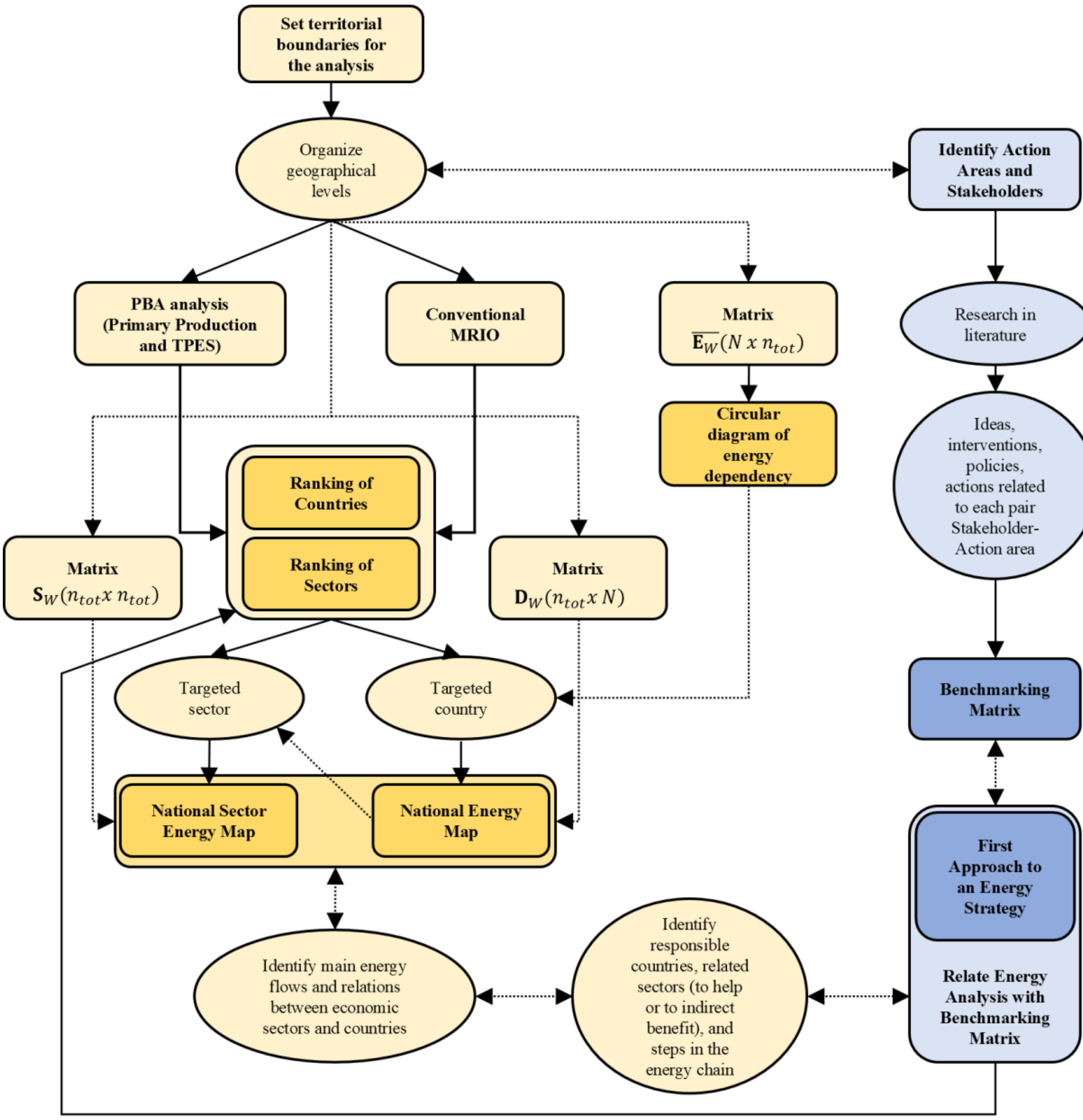

Figure 35. *Flow diagram for the energy analysis algorithm*

4 Study Case: Africa IEA

4.1 Study Case: Africa Benchmarking Process.

By requirement of the Africa-EU Energy Partnership (AEEP), the benchmarking process has been applied to Africa. The AEEP is a platform launched by African and European Heads of State and their governments in December 2007 inside the Africa-EU Joint Strategy framework. It is a long-term framework for political dialogue and cooperation between Africa and the European Union, and, under a partnership of equals, share knowhow and resources; tune their complementary interests; and closely link their policies to meet the energy challenge hand in hand. In the Energy Efficiency Workstream of AEEP, the development and dissemination of such a matrix is stated as responsibility of Politecnico di Milano. Taking profit of this situation, the study case is set to be done within the African context by using Eora26 [38] and IEA data [28]. Eora26 is a data base produced by M. Lenzen, D. Moran, K. Kanemoto and A. Geschke from The University of Sydney. The Eora multi-region input-output table database provides a time series of high resolution IO tables with matching environmental and social satellite accounts for 189 countries. In this case, the only satellite account considered is the fossil fuel energy intensity of economic sectors (which states for TFC + Losses + Own uses, i.e. a sort of TPES broke down by sectors). Economies are divided in 26 economic or productive sectors (a common 25 ISIC-type classification for economic sectors, adding an extra sector for re-import/re-export). The data used in this study case stands for the year 2013, but continuous data coverage from 1990 is available. Eora provides tables based on basic prices and on purchaser prices, in this study case basic prices tables are used since it is recommended when survey is related to environmental extended IO. The tables from Eora are built by using raw data from different sources, such as the UN's System of National Accounts, COMTRADE databases, Eurostat, IDE/JETRO, and numerous national agencies. Eora tables are produced by combining all the raw data via an optimization algorithm, in that way, during the optimization or matrix balancing process, elements that are supported by only few raw data, and hence restricted by only few constraints, can be subject to large adjustments, and hence their reliability is low. On the other hand, for virtually all large and important IO table elements, there exist supporting raw data, so that the adjustment of these elements is usually minimal, and hence their reliability is high. When CBA calculations requires an extracted-energy vector, it is built by using Primary Production data from IEA database, and allocating it into the Mining and Quarrying sector. Thinking on enhancement of energy efficiency in African continent, a deep research on specialized literature has been done. Since most of the African countries are catalogued as developing and undeveloped (or less-developed) countries [65,66], the benchmarking process have been focused on specific policies and energy interventions already successfully implemented on places like India, China, South America, or even some African countries. However, the research has been done taking as model the philosophy of European and North American energy system. The tables in **Appendix A** contain the results of the research of benchmarking process focused on the African context.

4.2 Analysis and conclusions on benchmarking process

As a complement for the benchmarking process, a proper analysis of the results is done. Such kind of analysis will provide useful information about the main stakeholders and action areas on which focus efforts for maximize the improvement on energy efficiency, in terms of number of interventions (i.e. specialized literature targets some stakeholders/action areas preferentially and often than others) but also it will help to identify possible lacks in literature which can represent a good opportunity for research.

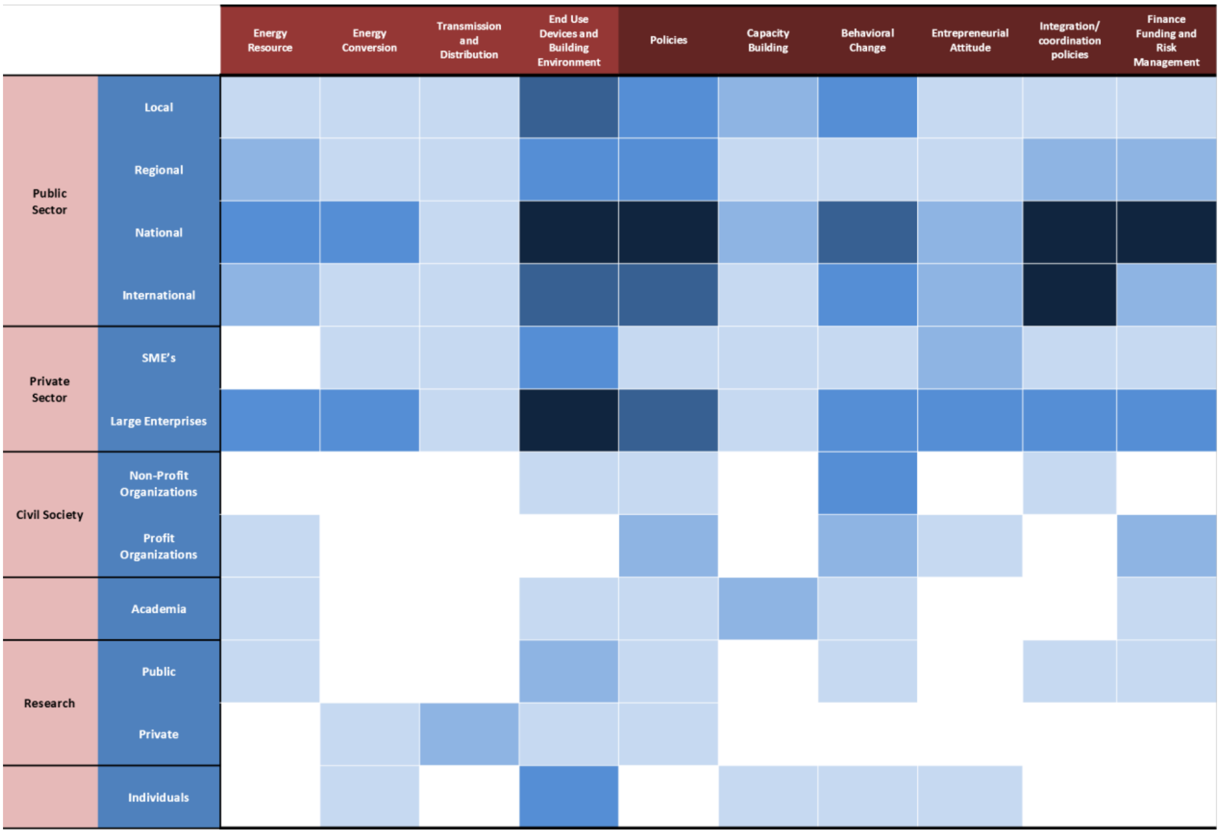

Figure 36. *Heat map matrix. Result of apply the Benchmarking process to Africa.*

However, a lack of literature doesn't necessarily mean a good opportunity for research, but a smaller importance of stakeholder/action areas. In addition, it is necessary to keep in mind the context of each pair stakeholder/action area, for example, all the pairs related to *Transmission and Distribution* have, apparently, low importance or a lack in research. However, this is not true, transmission and distribution systems are crucial on energy efficiency and large research have been focused on it. Nevertheless, interventions on transmission are very specific and mainly related to technology, materials, and logistics. Which results in a small number of energy actions on the matrix. According to the number of energy actions, policies, interventions, ideas… found by research in literature a color code has been built. The color code is useful in order to build a sort of heat map in the matrix, highlighting the stakeholders and action areas for which more policies, interventions or energy actions have been found in literature. This is an indication (but not evidence) about which are the most important and most relevant actors and areas towards energy efficiency. Since the benchmarking process should be done keeping in context the region or country to be analyzed, this information will be relevant when designing an energy strategy, and therefore, it is included in the process thanks to the benchmarking matrix.

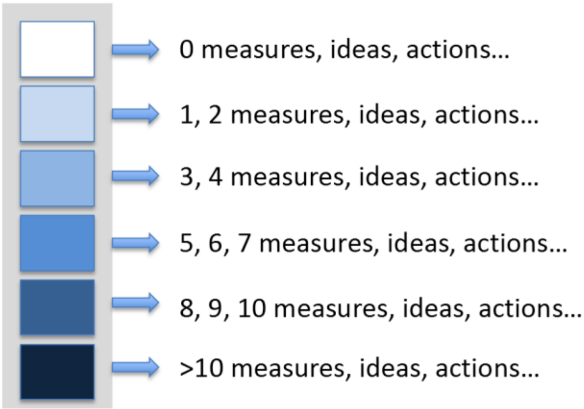

Figure 37. *Heat map matrix. Result of apply the Benchmarking process to Africa.*

About the built matrix, on one hand, it is possible to say that the more dynamic and responsible stakeholders will be the Public Sector, specifically the National and International Levels and the Private Sector, specifically the Large Enterprises. That is logic, because these sectors have the highest capacity and power to introduce changes and achieve significant repercussion and impact on the energy system. Consequently, one feasible possibility is to allow public national and international sector and private large enterprises to lead the energy strategy, while the rest of stakeholders would act as assistants or enhancers, helping along the process. On the other hand, it is possible to state that Academia is the stakeholder related to which less measures, interventions, etc., have been found on literature. In point of fact, contributions of Academia to an energy strategy are quite limited beyond capacity building, but it could be also representing that literature had not be focused on the possible contributions of academia to energy efficiency enhancement. Another worthy stakeholder is Civil Society, which surely could achieve a larger contribution to energy efficiency than that which literature suggests. Regarding to the action areas, it is easy to see that the more relevant and the ones which more measures englobe are End Use Devices & Building Environment, and Policies. The former is related to the final use of energy, so literature contains a lot of actions in order to promote responsible use, reduce wasted energy, achieve more efficient devices and empower eco-friendly environments. A wide range of stakeholders can be substantially involved with this action area, from public and private sectors to individual end users. The latter, policies, are the main mechanism governments and institutions have to achieve their targets and to introduce changes. Since energy policy-making issues concerns mainly to governments, literature includes a wide list of energy actions related, and most of them are, consequently, linked to the Public Sector. It is important to mention also the Finance, Funding & Risk Management, and Integration and Coordination of Policies action areas. The first is a critical issue involving energy efficiency since a large amount of money and investments are needed to exploit the potential beside energy efficiency, it will be necessary not only to account with public funding but also to attract private investors [15,56]. It is crucial to increase research and literature about the topic of financing and funding energy efficiency, due to its importance. Furthermore, the proper approach to discuss finances and risk towards energy efficiency must involve a larger number of stakeholders, and not be focused only on the public sector. In fact, other stakeholders as civil society, small and medium sized enterprises, or individuals, could have a relevant role financing energy efficiency by means of cooperative investing or crowdfunding for example, and this is a possibility very poorly explored on literature. Something similar happens with the second, Integration and Coordination of Policies. Again, literature forgets some stakeholders, such as Civil Society, that could have a key role in this action area.

Finally, as a preliminary approach to a possible energy strategy, a summary on the matrix content is done. According to the research, a good energy strategy for Africa, must be built around the international cooperation and coordination mainly between African countries. A strong and solid labelling policy for fuel and devices must be developed, and this policy will be stronger as much countries join it in a coordinated manner. Researchers, private companies, and political actors must agree about stablishing MEPS (Minimum Energy Performance Standards) for end use devices in order to accelerate new technologies arrival. Three main issues must be attended by public sector: Access to electric energy for the whole population at fair prices, fight against illegal connections to the grid [37], and against traditional fuel cooking [78]. Such kind of actions must be leaded by public sector, however, other stakeholders such as large private companies could play an important role on it. The third problem, which is related to the traditional fuels used for domestic cooking and heating (woodfire, kerosene, peat or coal among others) is a big and well known African problem [79,80]. This issue will require a joint effort by public and private sector in several action areas, not only energy conversion and end use devices, but also in behavioral change, and capacity building. It isn't a matter of just change or provide the proper equipment, but also to convince people to use it, and find who teach them and install it. Lastly, in order to provide energy security, economic benefits and exploit the huge renewable potential of Africa, African countries must agree and coordinate the empowerment of renewable energy deployment. Sources like wind, solar (thermal/photovoltaic), biomass & waste, hydraulic or tidal energy can substitute conventional fossil fuels in a wide range of applications improving the country energy security and achieving economic benefits and job creation, even they can be used for solving the problem of domestic traditional fuels.

4.3 Study Case: Africa Energy Analysis

In this section, the energy analysis for Africa is performed. Based on the statements made by Colombo et al. in [37] the analysis will be focused on 27 African countries (Africa IEA), out of a total of 58 countries as for UN geo-scheme of Africa, set in UNSTAT [81] due to the data availability. The list of countries can be consulted in Table 4. At the same time, these countries have been classified in 5 (6) sub-regions attending geographical and socio-economic criteria, in order to have a proper level of aggregation, especially for CBA calculations. The rest of the World has been also aggregated into regions, attending the criteria of World Bank for country classification by region [82]. The economic sectors included in the analysis are listed in the table below.

Word	Code
Agriculture	S1
Fishing	S2
Mining and Quarrying	S3
Food and Beverages	S4
Textiles and Wearing Apparel	S5
Wood and Paper	S6
Petroleum, Chemical and Non-Metallic Minerals	S7
Metal Products	S8
Electrical and Machinery	S9
Transport Equipment	S10
Other Manufacturing	S11

Recycling	S12
Electricity, Gas and Water	S13
Construction	S14
Maintenance and Repair	S15
Wholesale Trade	S16
Retail Trade	S17
Hotels and Restaurants	S18
Transport	S19
Post and Telecommunications	S20
Financial Intermediation and Business Activities	S21
Public Administration	S22
Education, Health and Other Services	S23
Private Households	S24
Others	S25
Re-Export and Re-import	S26
East Asia & Pacific	EAP
Europe & Central Asia	EUR
Latin America & The Caribbean	LAT
Middle East	ME
North America	NA
South Asia	SA
Eastern Africa	East
Northern Africa	North
Middle Africa	Middle
Western Africa	West
Southern Africa	South
South Africa	SouthA
Africa IEA	AFR

Table 3. *Analysis Legend*

Northern Africa	Middle Africa	Eastern Africa	Western Africa	Southern Africa
Algeria	Angola	Eritrea	Benin	Botswana
Egypt	Cameroon	Ethiopia	Cote d'Ivoire	Namibia
Lybia	Congo	Kenya	Ghana	
Morocco	Congo DR	Mozambique	Nigeria	South Africa*
Sudan	Gabon	Tanzania	Senegal	(regarding its
Tunisia		Zambia	Togo	Importance, it will
		Zimbabwe		Be treated as a region)

Table 4. *Sub-region aggregation for Africa IEA countries*

*South Africa: Despite the fact that this country is included in the aggregated sub-region of Southern Africa in some CBA calculations for sake of simplicity, in most of the diagrams and calculations, South Africa is considered as an independent region due to its great relevance as energy actor in Africa. As will be seen, South Africa, as single sub-region, is the main responsible of energy consumption directly and indirectly in Africa.

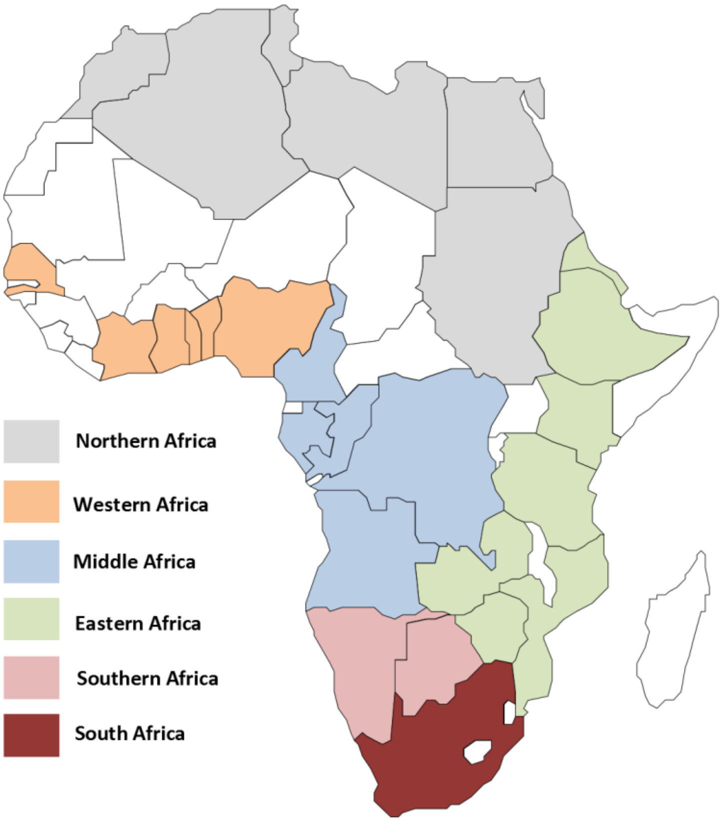

Figure 38. *Africa IEA and sub-regions.*

The analysis begins performing the conventional MRIO and PBA assessment, in order to build a ranking for countries and sectors. As can be seen in figure 35, South Africa alone as a single sub-region has a quite more relevant paper in the African energy scenario than Middle Africa or Eastern Africa for example. Very interesting statements can be done analyzing the following graph. Looking to the differences between Primary Production and TPES It is possible to identify some regions as important exporters of fossil fuel resources, as happens with Northern Africa, Western Africa and Middle Africa, or importers, like South Africa. This gives a first idea about the first-degree energy dependency of the sub-regions. If attention is payed to the difference between TPES and the Embodied Energy Consumption, a first approximation to the second-degree energy dependency could be stated. For example, South Africa “burns” much more fossil fuels than required to fulfill the final demand of its economic sectors. That means that the country is an important provider of intermediate products (i.e. products used in by other economic sectors as inputs for their production). In other words, that will mean that other countries have a second-degree energy dependency with respect to South Africa. So, establishing a preliminary ranking in terms of sub-regions according to its energy relevancy:

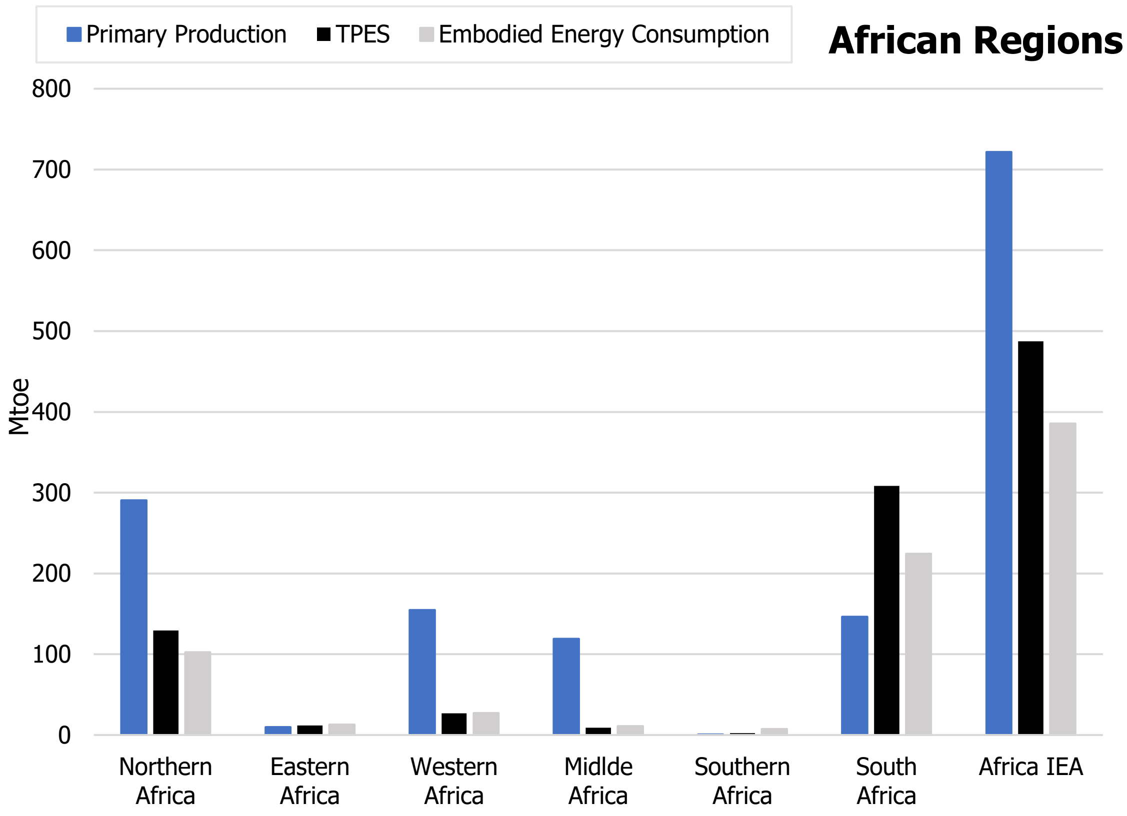

Figure 39. *Africa IEA regions according to the different energy accounting paradigms.*

	Primary Production (ktoe)	**TPES (ktoe)**	**Embodied Energy Consumption (ktoe)**
Northern Africa	290526 (40%)	129274.4 (27%)	102624.6 (27%)
Eastern Africa	9741 (1%)	11659.23 (2%)	13014.74 (3%)
Western Africa	154917 (21%)	26682.06 (5%)	27287.24 (7%)
Middle Africa	119309 (17%)	8850.68 (2%)	10847.61 (3%)
Southern Africa	843 (0.1%)	2454.483 (1%)	7388.34 (2%)
South Africa	146273 (19.9%)	308562.9 (63%)	224281.7 (58%)
Africa IEA	721609 (100%)	487483 (100%)	385444.2 (100%)

Table 5. *Sub-region ranking.*

As can be seen, the global region formed by Africa IEA countries has characteristics of a fossil fuels exporter, and burns more energy than the energy actually consumed (i.e. Africa IEA is an embodied energy exporter). In the same way, it is possible to say that South Africa is the main responsible of the energy “burnt” and consumed in Africa, but it is an importer of fossil fuels. The second region on energy importance, Northern

Africa, can be identified both as a fossil fuel and embodied energy exporter. Despite its very low volume of consumption, Eastern Africa and Southern Africa (Namibia and Botswana), could be classified as energy consumers since their embodied energy consumption is higher than their TPES or Primary Production. Moreover, Western and Middle Africa are clearly fossil fuel exporters while their TPES and Embodied Energy consumption are quite balanced. In the following point, Energy Maps corresponding to the mentioned African regions are showed. Then, we will focus in South Africa's more consuming sectors and in their relations with sectors from other regions in order to highlight hotspots and synergies for improve benefits from energy interventions and enhance collaboration between different stakeholders and countries. In a deeper level, is possible to stablish a ranking of countries, evaluating its energy relevancy by evaluating its embodied energy consumption, its TPES, and its fossil fuel primary energy production, in that order. The following table stablish a ranking of countries in terms of energy, analyzing the different indicators stated before. Again, South Africa shows itself as the main energy consumer in the African country.

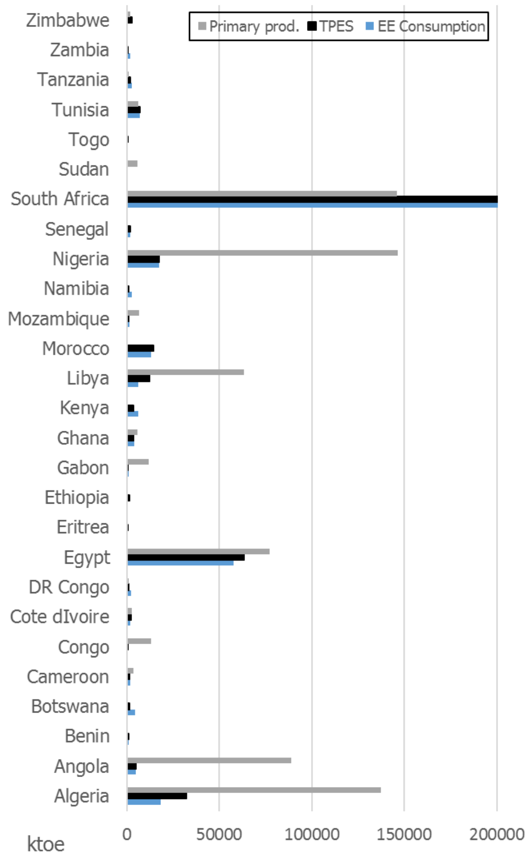

Figure 40. Africa IEA countries (CBA and PBA).

EE Consumption	TPES	Primary Production
South Africa	South Africa	Nigeria
Egypt	Egypt	South Africa
Algeria	Algeria	Algeria
Nigeria	Nigeria	Angola
Morocco	Morocco	Egypt
Tunisia	Libya	Libya
Kenya	Tunisia	Congo
Libya	Angola	Gabon
Angola	Ghana	Mozambique
Botswana	Kenya	Tunisia
Ghana	Zimbabwe	Sudan
Namibia	Cote d'Ivoire	Ghana
Tanzania	Tanzania	Cameroon
DR Congo	Senegal	Cote d'Ivoire
Senegal	Ethiopia	Zimbabwe
Cote d'Ivoire	Cameroon	DR Congo
Zambia	Botswana	Tanzania
Cameroon	Benin	Botswana
Mozambique	Namibia	Morocco
Benin	DR Congo	Zambia
Gabon	Mozambique	Senegal
Congo	Congo	Benin
Togo	Gabon	Eritrea
Ethiopia	Zambia	Ethiopia
Eritrea	Togo	Kenya
Zimbabwe	Eritrea	Namibia
Sudan	Sudan	Togo

***Table 6.** Country ranking.*

However, it is also interesting to build a ranking highlighting the energy per capita. Since the main target is maximize benefits from an efficiency improvement or from an increase in energy savings, it will be proper to focus in the previous ranking. Nevertheless, a ranking of countries based on energy per capita will be a useful support information in order to keep the country context while developing the analysis

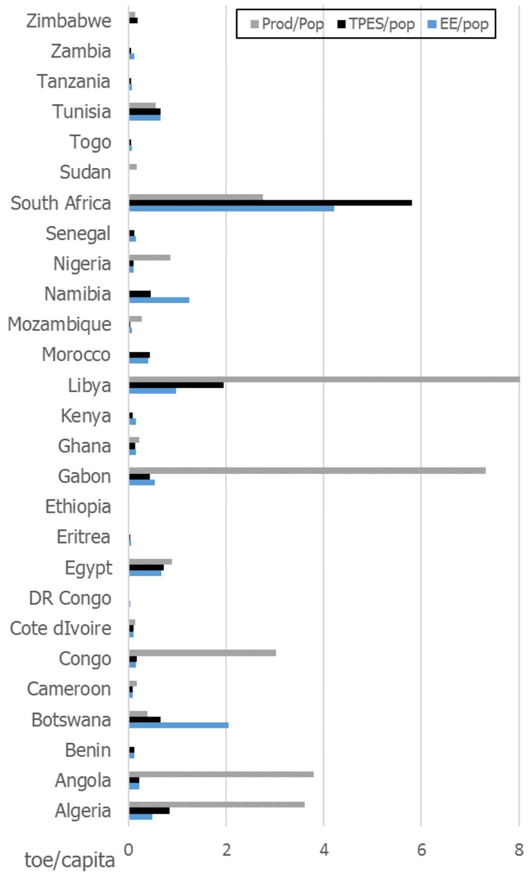

__Figure 41.__ Africa IEA countries (CBA and PBA) per capita.

EE Cons./capita	TPES/capita	Primary prod./c
South Africa	South Africa	Libya
Botswana	Libya	Gabon
Namibia	Algeria	Angola
Libya	Egypt	Algeria
Egypt	Tunisia	Congo
Tunisia	Botswana	South Africa
Gabon	Namibia	Egypt
Algeria	Morocco	Nigeria
Morocco	Gabon	Tunisia
Angola	Angola	Botswana
Ghana	Zimbabwe	Mozambique
Congo	Congo	Ghana
Senegal	Ghana	Cameroon
Kenya	Senegal	Sudan
Benin	Benin	Cote d'Ivoire
Zambia	Cote d'Ivoire	Zimbabwe
Nigeria	Nigeria	Tanzania
Cote d'Ivoire	Kenya	DR Congo
Cameroon	Cameroon	Zambia
Togo	Togo	Morocco
Mozambique	Zambia	Senegal
Tanzania	Tanzania	Benin
Eritrea	Mozambique	Eritrea
DR Congo	Eritrea	Ethiopia
Zimbabwe	Ethiopia	Kenya
Ethiopia	DR Congo	Namibia
Sudan	Sudan	Togo

__Table 7.__ Country ranking (per capita).

Very interesting considerations could be extracted from both rankings. First of all, and since it is leading most of the rankings, the first country to be targeted and set as preferential for energy interventions is South Africa. It is the main contributor to the African continent energy consumption, and it is also an important producer of fossil fuels resources. A special characteristic of fossil fuel energy scenario in South Africa should be foregrounded: its TPES is higher than its embodied energy consumption. This means that South Africa is an exporter of embodied energy. Consequently, some countries will have a second-degree energy dependency with respect to South Africa, (i.e. other countries will be benefited indirectly if South Africa improves the energy efficiency in its productive processes or, oppositely if other countries require less inputs for their productive processes, South Africa would need to burn less fossil fuels). From this statement, a special attention should be payed to Namibia and Botswana (Southern Africa), neighboring countries of South Africa, which both increase significantly its energy consumption from TPES to Embodied energy consumption.

Furthermore, it is also relevant the group of countries that can be classified as important fossil fuel exporters (Algeria, Libya, Angola, Congo, Nigeria, and Gabon). This circumstance could be profited to create a fossil fuel exporter market in Africa, dedicated to finance the efficiency improvements and the development and deploy of renewable energies, since finance and investments are a critical issue in this fields and, for sure, the public budget will not be enough to achieve the necessary funds. Despite the fact that this is just an idea, and it would be quite complicated form economic and politic point of view, it proves that is not too bad to have that information about primary production.

Then, in order to have a more accurate vision about the energy dependency (first-degree and second-degree), the paradigm of the "*Origin of energy embodied in consumed goods and services"* is applied. This paradigm, when applied with an energy vector based on primary production, will reflect both the first-degree energy dependency among countries (since the energy accounted is primary produced), and second-degree energy dependency (since it is a CBA method and reflects inputs transactions between countries and economic sectors). The circular diagram of figure 38 reflects the results of the calculations. The thickness of the links between countries are proportional to the energy "sent" from one country to another (e.g. South Africa receives a small amount from Botswana, but Botswana receives a large amount from South Africa). Beside the country names, the number reflects the total amount of energy received by each country from others. What gives an idea of the energy dependency of each country.

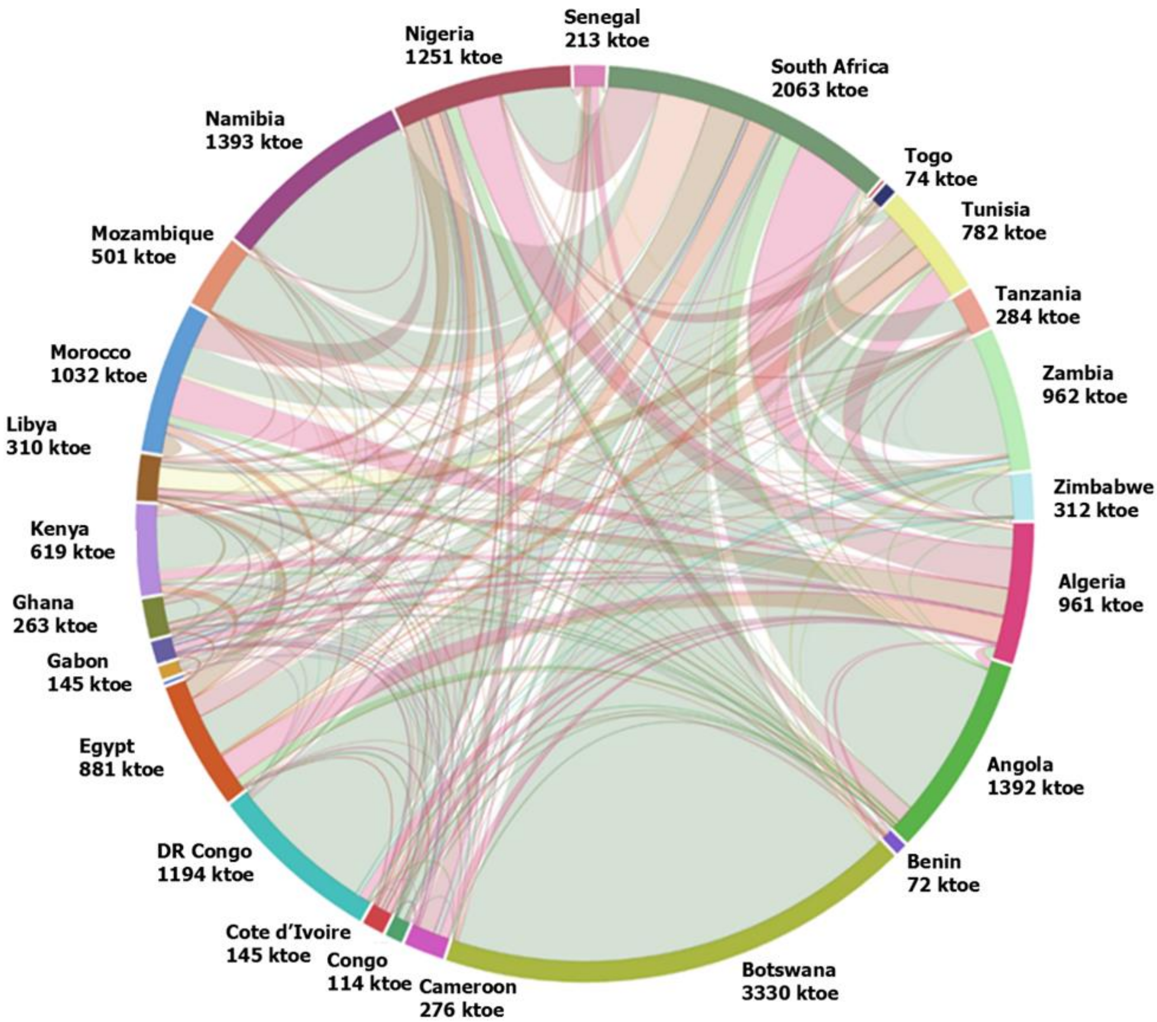

Figure 42. *1st and 2nd Energy dependencies between African Countries.*

For sake of simplicity, and for a better representation, the embodied energy from resource extraction used by each country to produce the final demand of their own sectors has not been represented (i.e. the diagram only reflects the relationships of countries with others, but not with themselves) and also the rest of the World countries have been excluded (remember: results come from a MRIO approach). As raised before, the diagram confirms an important interaction between South Africa and the sub-region of Southern Africa (Namibia and Botswana). Meaning both countries depend on energy resources and embodied energy inputs from South Africa.

Then, the Energy Maps of the different African regions are presented and discussed. The main energy consumer economic sectors are listed, being identified as energy hotspots. These hotspots are listed regarding to the energy burnt by them (i.e. their TPES), or by their direct and indirect energy requirements (i.e. their Embodied Energy Consumption). For the case of South Africa, the analysis goes deeper to a sectorial level and the Sectorial Energy Maps are used to expose links between economic sectors and other regions, focusing on the hotspots highlighted by terms of the National Energy Map. The figure below, represents the National Energy Map built for the sub-region of Northern Africa, the first group of columns (left) represent the TPES per sector, the second column highlights the difference between TPES of the region (left part of the column) and embodied energy consumption (right part of the column). In the case of Northern Africa, TPES is higher than the embodied energy consumption. The third group of columns shows the origin of the embodied energy consumed in Northern Africa, most of it is provided by itself, but it receives quantities relatively important from Europe & West Asia, and from East Asia & Pacific. The third group of columns, reflects the embodied energy consumption by each sector in Northern Africa. The energy consumed varies importantly when compared with the TPES required per each sector, exposing hidden energy consumer sectors, such as Construction, or Public Administration. The last group of columns (right) shows where the goods and services produced inside Northern Africa are consumed as final demand by individuals, in terms of embodied energy. The rest of the National Energy Maps can be read under the same terms.

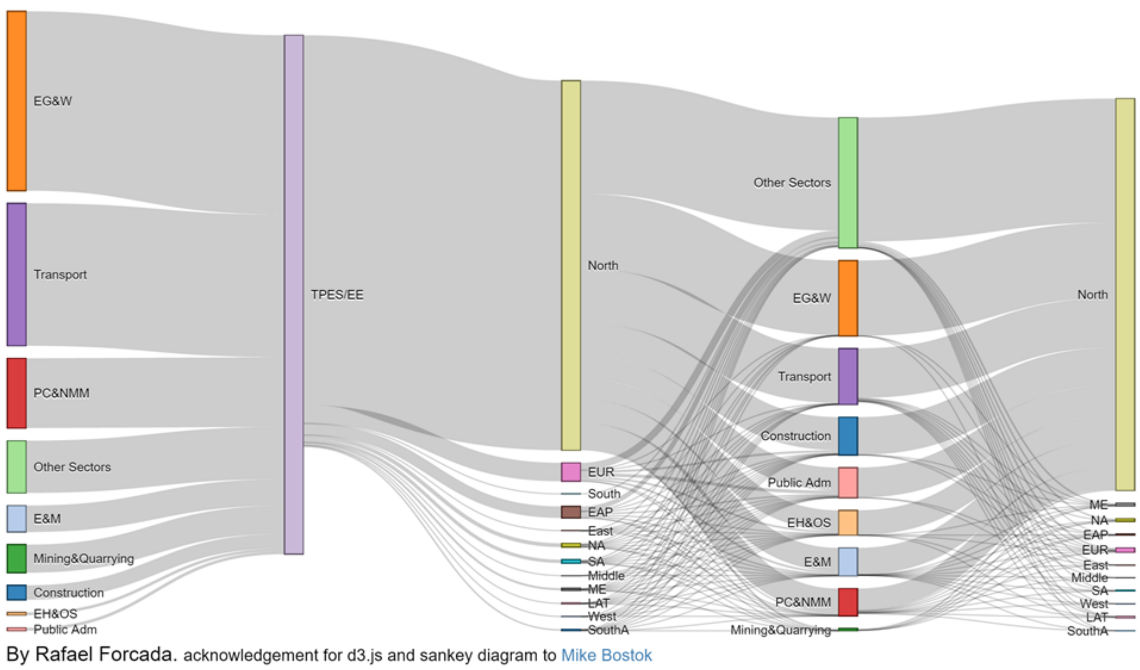

Figure 43. *National Energy Map for Northern Africa.*

Northern Africa sectoral energy assessment			
TPES		**Embodied Energy Consumption**	
Ranking	**Value (ktoe)**	**Ranking**	**Value (ktoe)**
Electricity, Gas & Water	44678 (35%)	*Electricity, gas & Water*	18770 (18%)
Transport	35526 (28%)	*Transport*	13983 (14%)
Petroleum, Chemicals and Non-Metallic Minerals	17369 (13%)	*Construction*	9436 (9%)
Mining & Quarrying	6996 (5%)	*Public Administration*	7521 (7%)
Electrical & Machinery	6626 (5%)	*Education, Health & Other Services*	6230 (6%)

Table 8. *Sector ranking in Northern Africa.*

Two critical sectors are Transport, and Electricity Gas & Water (EG&W), since they lead both rankings. However, it is noticed that their TPES is quite higher than their Embodied Energy Consumption, what means that they are providing energy to other sectors. On the other hand, sectors as Construction, Public Administration or Education, Health & Other Services (EH&OS), have a very low direct energy requirements but they invoke great amounts of embodied energy from other sectors. From a geographical point of view, it can be said that most of the embodied energy consumed by Northern Africa is domestically burnt, with small contributions from other global regions, specially Europe & West Asia (EUR) and East Asia & Pacific (EAP). The consumption by individuals of goods and services produced by this region is mainly domestic (95,2%), with small exports, principally to EUR, North America (NA) and Middle East (ME).

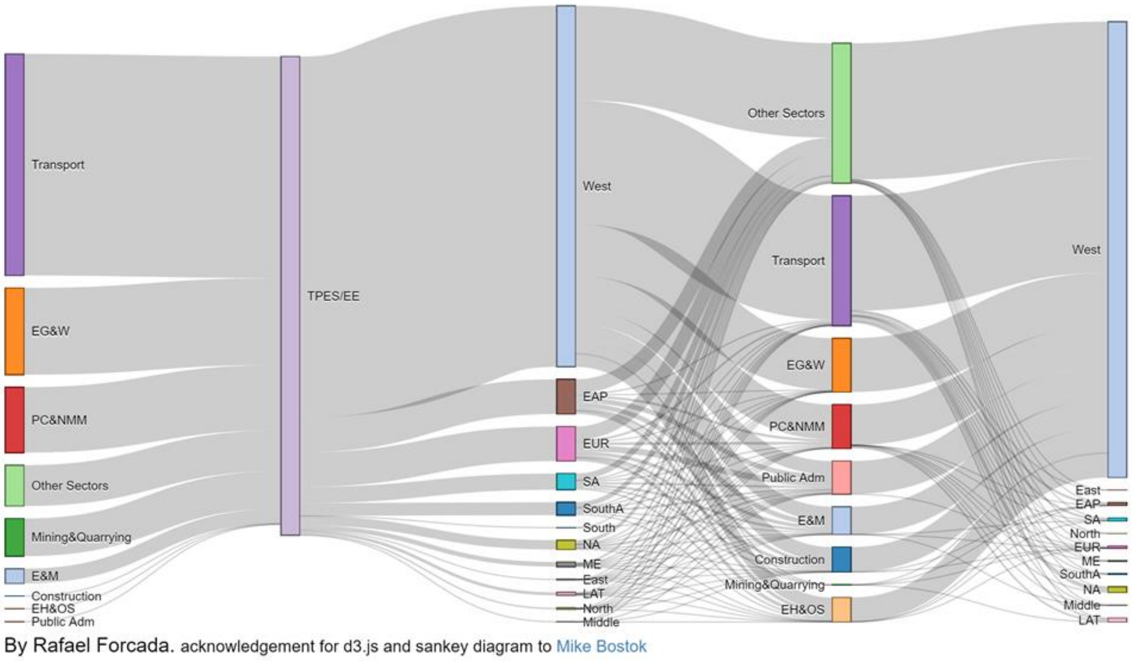

Figure 44. *National Energy Map for Western Africa.*

Western Africa sectoral energy assessment			
TPES		**Embodied Energy Consumption**	
Ranking	**Value (ktoe)**	**Ranking**	**Value (ktoe)**
Transport	12628 (47%)	*Transport*	7404 (27%)
Electricity, Gas & Water	4947 (19%)	*Electricity, Gas & Water*	3072 (11%)
Petroleum, Chemicals and Non-Metallic Minerals	3730 (14%)	*Petroleum, Chemicals & Non-Metallic Minerals*	2508 (9%)
Mining & Quarrying	2146 (8%)	*Public Administration*	1888 (7%)
Electrical & Machinery	838 (3%)	*Electrical & Machinery*	1593 (6%)

Table 9. *Sector ranking for Western Africa.*

In the case of Western Africa, the situation is similar to the previous one, being Transport and EG&W the two key sectors from an energy point of view. In the consumption based side, things do not change very much with respect to the production-based side, with the exception of the Public Administration, that belongs to a kind of economic sectors that have quite small direct energy requirements, but large indirect energy requirements (such as Construction or EH&OS, for example). The energy burnt by Western Africa and their Embodied Energy Consumption are quite balanced, however, this African sub-region imports an important share of its embodied energy consumption (about 25%), and mainly from EAP (7,2%), EUR (7,2%), South Asia (SA) (3,4%) and South Africa (SouthA) (2,7%). The energy embodied in the goods and services produced by Western African economic sectors is consumed in a predominantly domestic way (95,2%), such as in Northern African case.

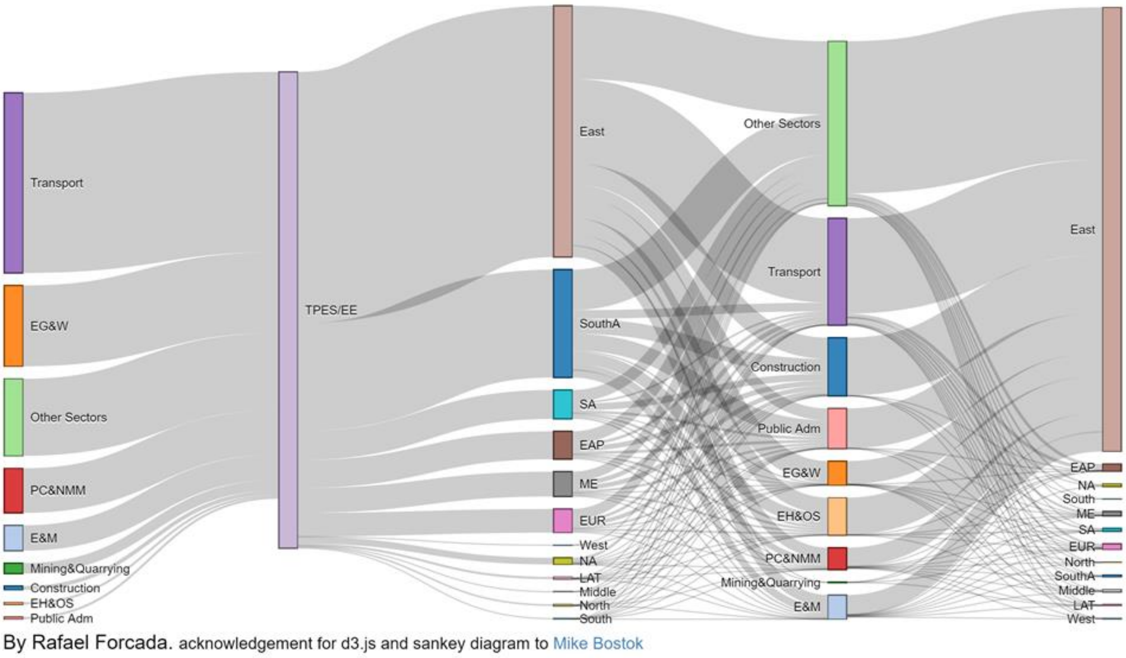

Figure 45. *National Energy Map for Eastern Africa.*

Eastern Africa sectoral energy assessment			
TPES		**Embodied Energy Consumption**	
Ranking	**Value (ktoe)**	**Ranking**	**Value (ktoe)**
Transport	4923 (42%)	*Transport*	2922 (23%)
Electricity, Gas & Water	2209 (19%)	*Construction*	1593 (12%)
Petroleum, Chemicals and Non-Metallic Minerals	1218 (10%)	*Public Administration*	1097 (8%)
Electrical & Machinery	692 (6%)	*Education, Health & Other Services*	1027 (8%)
Mining & Quarrying	285 (2%)	*Electrical & Machinery*	661 (5%)

Table 10. *Sector ranking for Eastern Africa.*

In Eastern African economies, the sectors with the most important direct energy requirements remains basically the same as in the previous case. However, regarding the consumption-based side, Construction, Public Administration and EH&OS overcome EG&W this time. This is very relevant since EG&W is the second sector that most energy requires directly, representing the 19% of the TPES of the country, while the others have very small direct energy requirements. This is representative of the differences when accounting energy from production-based or a consumption-based point of view. The physical meaning of this is that the direct energy requirements of EG&W is so large because other sectors are requiring energy indirectly from it. Eastern African economies consumes more embodied energy than their TPES, which means that these economies are importing embodied energy in order to fulfill the energy requirements of their economic sectors. Specifically, Eastern African economies import the 47% of their embodied energy consumption, mainly from South Africa (22,7%), South Asia (6,1%), East Asia & Pacific (5,9%) and Middle East (5,2%). One more time, the energy embodied in goods and services consumed by individuals as final demand is consumed mainly domestically (93,2%).

Middle Africa sectoral energy assessment			
TPES		**Embodied Energy Consumption**	
Ranking	**Value (ktoe)**	**Ranking**	**Value (ktoe)**
Transport	4572 (52%)	*Public Administration*	1544 (14%)
Electricity, Gas & Water	1311 (15%)	*Transport*	1451 (13%)
Petroleum, Chemicals and Non-Metallic Minerals	993 (11%)	*Education, Health & Other Services*	1441 (13%)
Electrical & Machinery	637 (7%)	*Construction*	1108 (10%)
Education, Health & Other Services	162 (2%)	*Electrical & Machinery*	858 (8%)

Table 11. *Sector ranking for Middle Africa.*

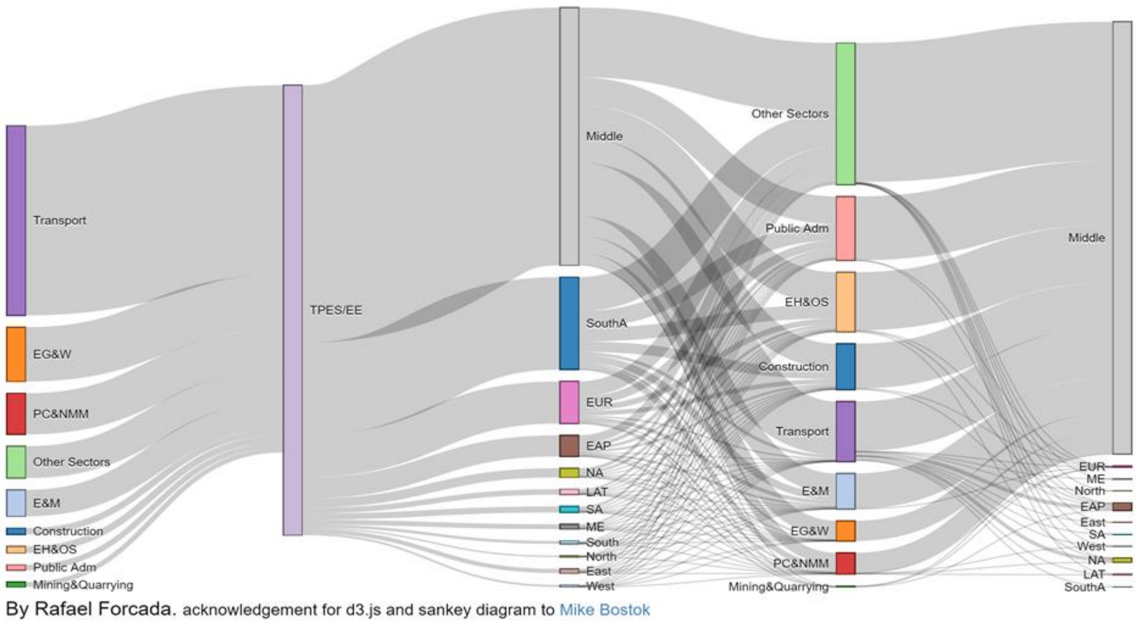

Figure 46. *National Energy Map for Middle Africa*

For Middle African economies, even Transport sector is exceeded by Public Administration in the consumption based side. Anyway, Middle African economies are the countries which less energy consume in Africa, both from production-based or consumption-based points of view. Middle Africa, like Eastern Africa, imports most of its embodied energy consumption (43%). Mainly from South Africa (20,6%), Europe & West Asia (9,4%) and East Asia & Pacific (4,7%). The production of Middle African economic sectors is again consumed inside their boundaries (96,1%), the next region consuming Middle African goods and services is East Asia & Pacific (1,7%). Thanks to the previous results, it is easy to conclude that any initiative towards sustainable development or reduction of fossil fuel consumption at African level needs to be leaded by South Africa. And by means of the national and sectoral energy maps, energy hotspots and energy links or synergies between South African economic sectors and other countries' economic sectors can be exposed, helping in the design of an energy strategy and aiming to international cooperation.

South Africa sectoral energy assessment			
TPES		**Embodied Energy Consumption**	
Ranking	**Value (ktoe)**	**Ranking**	**Value (ktoe)**
Electricity, Gas & Water	114120 (37%)	*Electricity, gas & Water*	45751 (20%)
Transport	84112 (27%)	*Transport*	36622 (16%)
Petroleum, Chemicals and Non-Metallic Minerals	41283 (13%)	*Food & Beverages*	21254 (9%)
Metal Products	15291 (5%)	*Construction*	15983 (7%)
Mining and Quarrying	11124 (4%)	*Public Administration*	12615 (6%)

Table 12. *Sector ranking for South Africa*

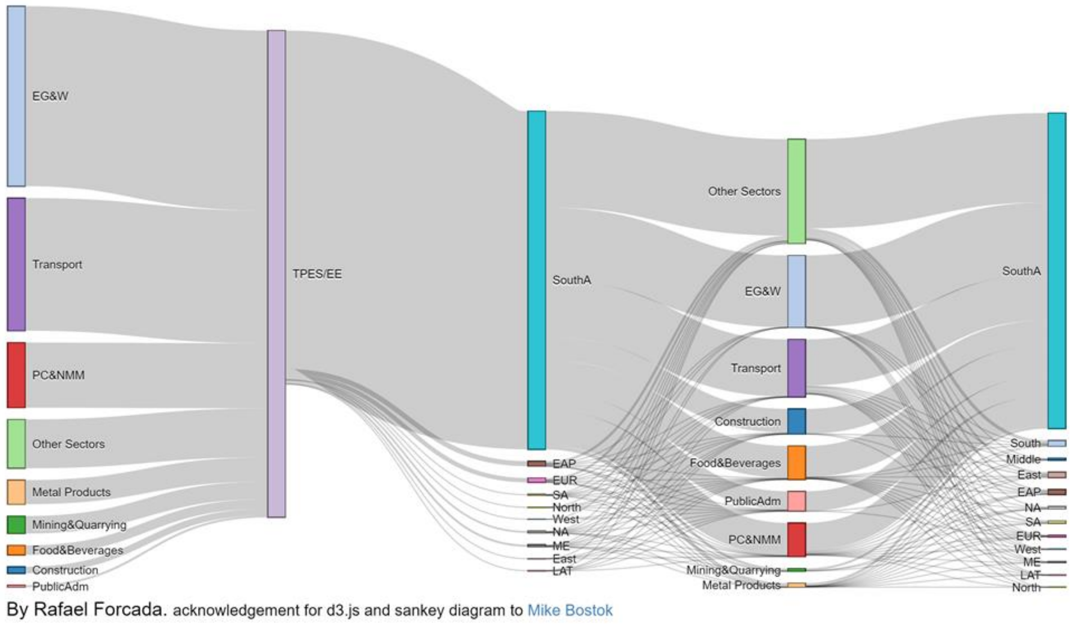

Figure 47. *National Energy Map for South Africa*

South Africa is the African country (and region) most energy consumer. As analyzed before, its TPES is quite bigger than its Embodied Energy Consumption, what implies that it provides embodied energy to the surrounding regions. As in some previous cases, Transport and EG&W seem to be the critical sectors of South Africa when speaking about energy. Since this country is the most energy consumer by far, these two sectors are the main energy hotspots in Africa. However, when regarding the difference between the TPES of these sectors and their Embodied Energy Consumption (which is less than the half of their TPES), is highlighted that South African Transport and EG&W present so large consumption patterns because they are supporting the production of other sectors and countries. Thus, in order to reduce their TPES, actions could be taken in other sectors and reduce it indirectly.

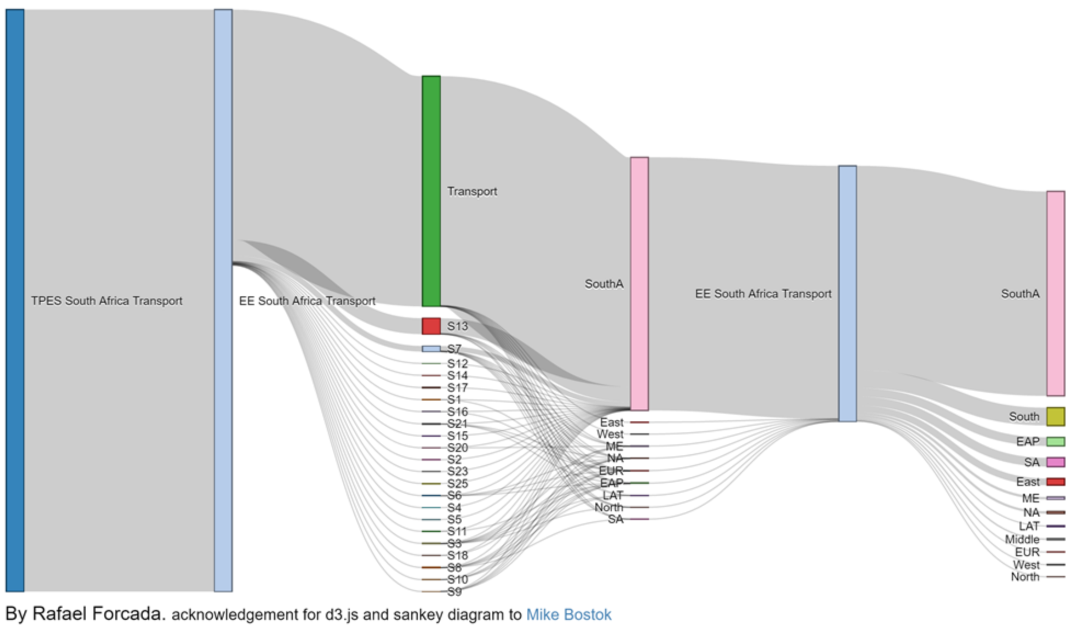

Figure 48. *Sectoral Energy Map for South Africa Transport*

In fact, when analyzing the Sectorial Energy maps for Transport and EG&W in South Africa we realize that both sectors have very similar characteristics. Their TPES (represented by the first column to the left) is much larger than their Embodied Energy Consumption (represented by the right side of the second column) (their Embodied Energy Consumption represents 43,9% of TPES in the case of Transport, and 40,3% in the case of EG&W) what means that both sectors support the production of other sectors, from an energy point of view. In addition, most of their embodied energy consumption is invoked from themselves, (97,7% in the case of Electricity, Gas & Water, and 89,8% in the case of Transport), what means that they are self-sufficient sectors.

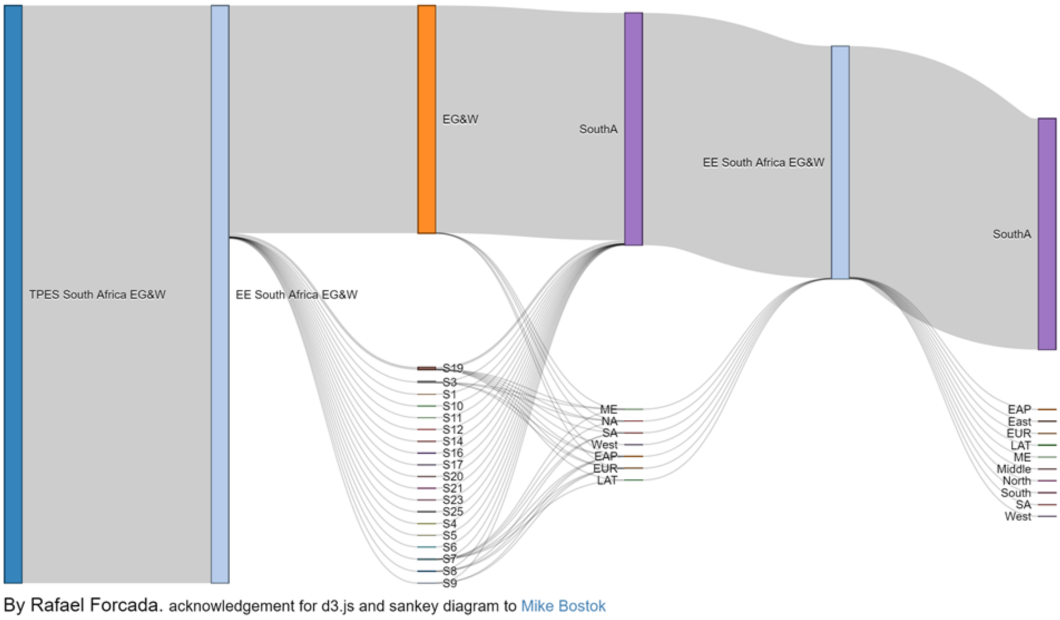

Figure 49. *Sectoral Energy Map for South Africa EG&W*

Moreover, the final consumption by individuals is predominantly domestic in both cases, 79,9% in the case of Transport, with small exports to Southern Africa (7%) and East Asia & Pacific and South Asia (3,5% in both cases). For EG&W the domestic consumption by individuals represents 99,2% of the embodied energy consumed by the sector. On the other hand, this shape of the energy metabolism means that there will be several sectors supplied by Transport and Electricity Gas & Water. Looking to the National Energy Map may be argued that, possibly, two of the main sectors receiving energy from Transport and EG&W are Food & Beverages and Construction. However, to confirm that it will be necessary to analyze the corresponding sectorial maps. Effectively, both sectors depend importantly on Transport and EG&W (besides on themselves and Petroleum, Chemicals & Non-Metallic Minerals (PC&NMM) in the case of Construction, and on Agriculture in the case of Food & Beverages). In terms of countries or regions, the main supplier is South Africa, since as stated before South Africa is an embodied energy exporter. This relationship is reciprocal, the implication is that the increase of technological efficiency on the supplier sector, will bring economic benefits (since the same output could be achieved by using less fossil fuels) to the supported sector. But also, if the supported sector finds a way of use wisely the embodied energy invoked, or reduce its consumption of it, the TPES of the supplier sector will be reduced. In other words, if the goal is to reduce the fossil fuel TPES of Transport or EG&W, policy makers can proceed in three ways according with the concepts stated before:

a) Shift to renewable sources. In this case, the fossil fuel TPES will be reduced, but the amount of energy used will remain the same. The supported sector will be benefited only if the renewable energy is cheaper than the equivalent amount of fossil fuel energy.

b) Increase the technological energy efficiency of the supplier sector. This case will bring benefits to the supported sector too. Thus, it may be possible to encourage supported sector to help and participate actively in the efforts to enhance technological energy efficiency of supplier sectors.

c) Reduce the energy invoked from supplier sector by reducing the demand of supported sectors by technical, organizational, institutional, structural or behavioral changes in their productive activities. Or reduce final demand by individuals, however this will represent a decrease in the economic profit of the sector. In this case, by reducing the embodied energy consumption of other sectors it is possible to reduce the fossil fuel TPES of the targeted sector.

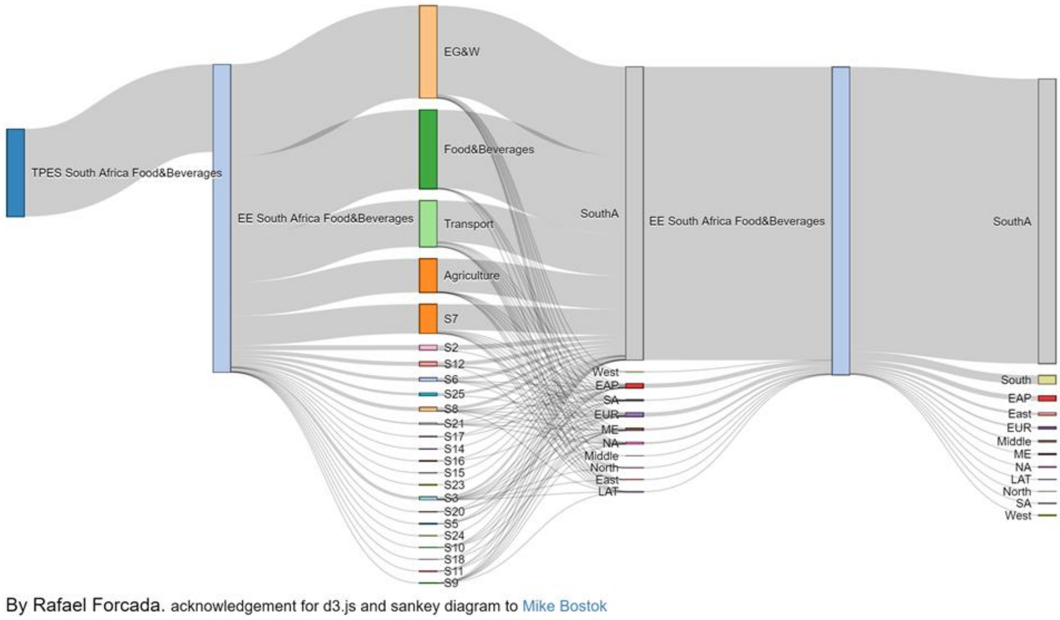

Figure 50. *Sectoral Energy Map for South Africa Food & Beverages*

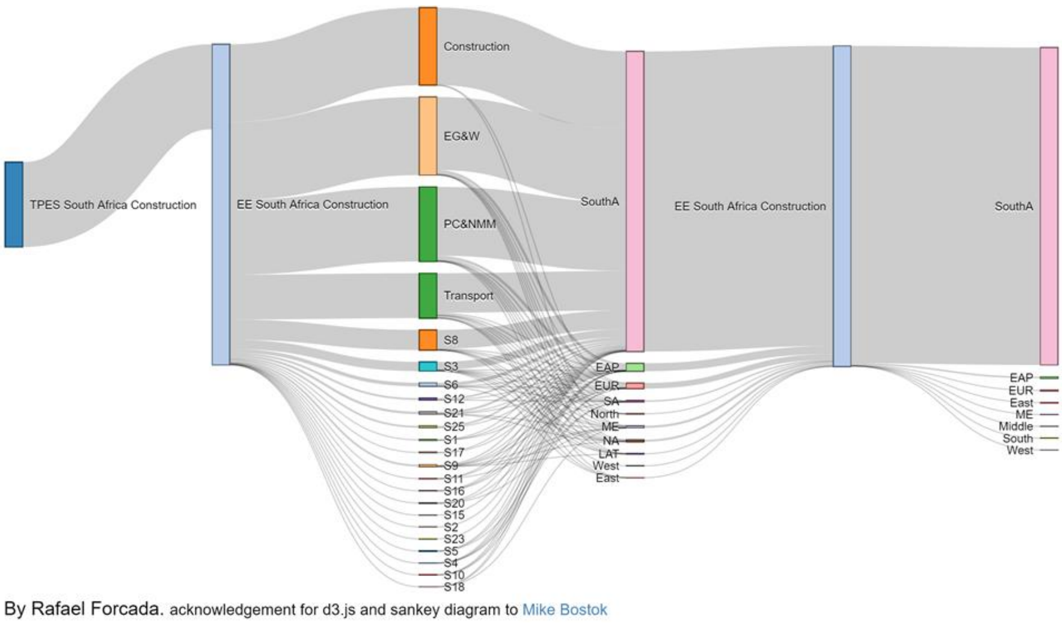

Figure 51. *Sectoral Energy Map for South Africa Construction*

In this specific case, Food & Beverages sector invokes 6161 ktoe from EG&W (29% of its embodied energy consumption) and 2854 ktoe from Transport (14%). And Construction invokes 3642 ktoe (23%) from EG&W and 1968 ktoe (12%) from Transport.

South Africa. Food & Beverages			
Energy Consumption	***Suppliers***		***Consumers (% of EE)***
Embodied Energy (ktoe)	*Country (% of EE)*	*Sector (% of EE)*	
21248	South Africa (95%)	EG&W (29%) Food & Beverages (25%) Transport (14%) Agriculture (10%)	South Africa (92%)

Table 13. *South African Food & Beverages energy analysis.*

South Africa. Construction			
Energy Consumption	***Suppliers***		***Consumers (% of EE)***
Embodied Energy (ktoe)	*Country (% of EE)*	*Sector (% of EE)*	
15985	South Africa (94%)	Construction (24%) EG&W (23%) PC&NMM (22%) Transport (12%)	South Africa (99%)

Table 14. *South African Construction energy analysis*

In addition, the energy relationships between sectors are not constrained to the national territorial boundaries. As highlighted in the analysis of previous National Energy Maps, several African sub-regions import significant quantities of embodied energy from South Africa, and probably, due to their characteristics, that embodied energy comes from Transport and EG&W. For example, Western Africa imports 735 ktoe from South Africa, what represents the 2,7% of its embodied energy consumption. Eastern Africa imports 2948 ktoe (22,7% of its embodied energy consumption) from South Africa. And Middle Africa imports 2230 ktoe (20,7% of its embodied energy consumption) of embodied energy from South Africa. But more representative is the case of Southern Africa (i.e. Namibia and Botswana), which imports 4911 ktoe from South Africa, what represents 66,5% of its embodied energy consumption. In the figure and the table below the National Energy Map for Southern Africa is presented. As it can be seen the contribution of South Africa represent the major share of its embodied energy consumption, and this contribution is especially big for Public Administration (77,5% of the embodied energy consumed by this sector), and Construction (68,8%).

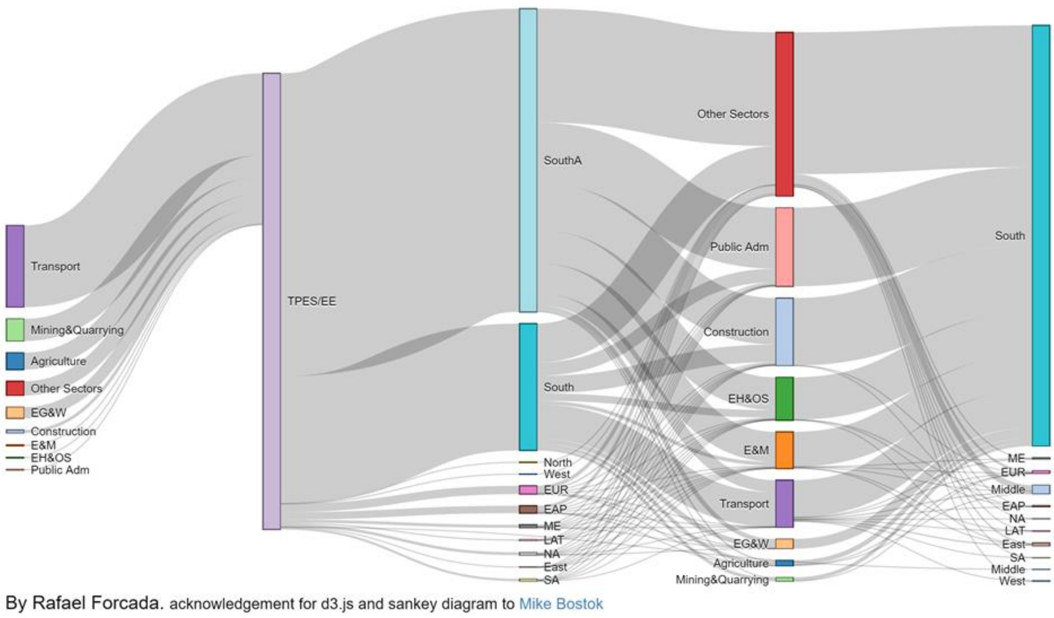

Figure 52. *National Energy Map for Southern Africa*

Southern Africa sectoral energy assessment			
TPES		**Embodied Energy Consumption**	
Ranking	**Value (ktoe)**	**Ranking**	**Value (ktoe)**
Transport	1324 (54%)	*Public Administration*	1276 (17%)
Mining & Quarrying	359 (15%)	*Construction*	1097 (15%)
Agriculture	274 (11%)	*Transport*	763 (10%)
Electricity, Gas & Water	181 (7%)	*Education, Health & Other Services*	697 (9%)
Others	171 (7%)	*Electrical & Machinery*	595 (8%)

Table 15. *Sector ranking for Southern Africa*

If the Sectorial Energy Maps of Public Administration and Construction sectors for Southern Africa are analyzed, their energy relationships with South Africa can be further exposed. For Construction sector, the share of embodied energy consumption is of 69% for South Africa and 25,8% for Southern Africa. Furthermore, with this kind of map it is possible to see from which specific sectors come that embodied energy. 189 ktoe (representing 17% of the embodied energy consumption of Construction) come from South African Transport, and 209 ktoe (19%) from South African EG&W. Another sector that makes an important contribution is PC&NMM, which represent the 15% of the embodied energy consumption of Construction. In the case of Public Administration, the share of embodied energy is 78% for South Africa and 17% for Southern Africa.

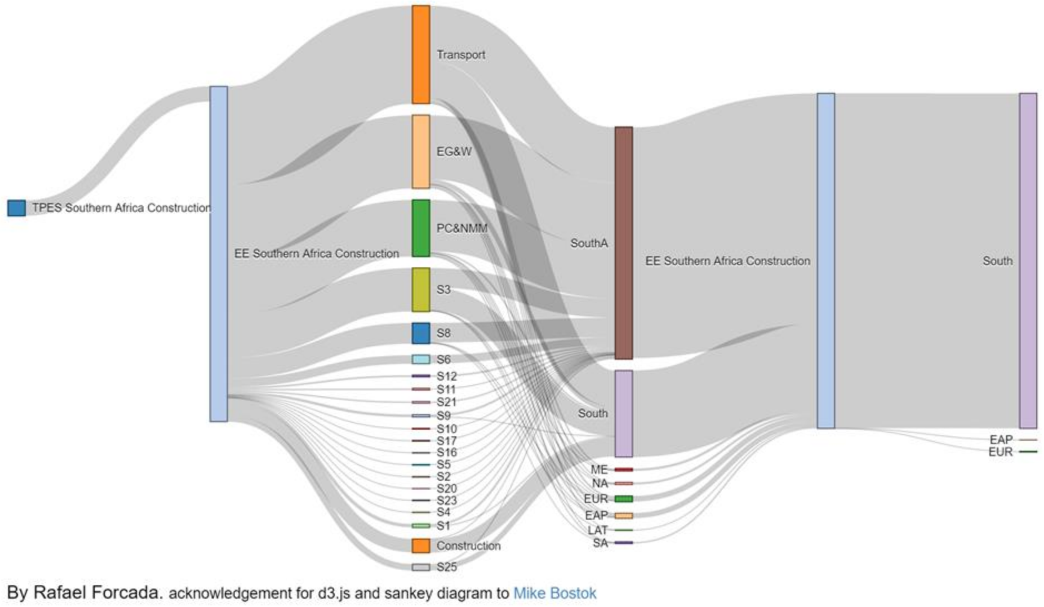

Figure 53. *Sectoral Energy Map for Southern Africa Construction*

Southern Africa. Construction			
Energy Consumption	***Suppliers***		***Consumers (% of EE)***
Embodied Energy (ktoe)	*Country (% of EE)*	*Sector (% of EE)*	
1096	South Africa (69%)	EG&W (19%)	Southern Africa (99%)
		Transport (17%)	
		PC&NMM (15%)	
	Southern Africa (26%)	Transport (11%)	
		Mining & Quarrying (7%)	
		Construction (4%)	

Table 16. *Southern African Construction energy analysis.*

And the embodied energy that comes from South Africa is provided mainly by Transport sector (496 ktoe, which represents 39% of the embodied energy consumption of Public Administration in Southern Africa), by EG&W (188 ktoe, 15% of Public Administration embodied energy consumption), and by PC&NMM (164 ktoe, 13%). Thus, it can be stated that these two Southern African sectors are importantly supported by the main South African energy hotspots.

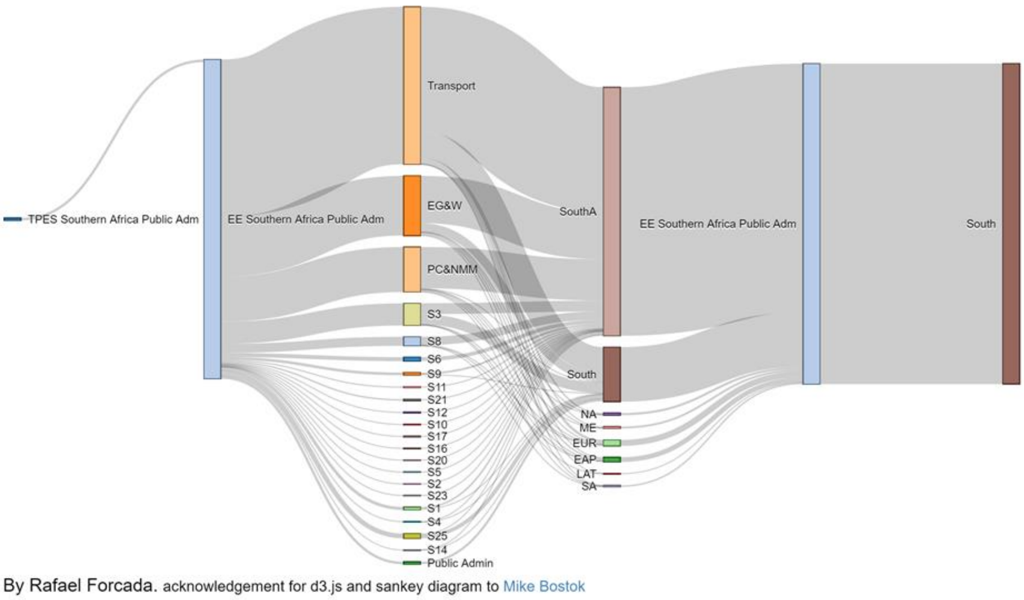

Figure 54. *Sectoral Energy Map for Southern Africa Public Administration*

Southern Africa. Public Administration.			
Energy Consumption	***Suppliers***		***Consumers (% of EE)***
Embodied Energy (ktoe)	*Country (% of EE)*	*Sector (% of EE)*	
1269	South Africa (78%)	Transport (39%)	Southern Africa (100%)
		EG&W (15%)	
		PC&NMM (13%)	
	Southern Africa (17%)	Transport (8%)	
		EG&W (3%)	

Table 17. *Southern African Public Administration energy analysis.*

At the end, just the 39,4% of the South African EG&W TPES is actually consumed by that sector, and in the case of South African Transport, the real consumption corresponds to the 39,1% of the sectorial TPES. The rest of the energy is consumed by other sectors in the country and abroad. In that way, it is possible to design an energy strategy involving several sectors and several regions. For example, South Africa could implement a policy of Minimum Energy Performance Standard (MEPS) for Construction activities, in order to minimize the embodied energy required from EG&W. At the same time, by enhancing the deployment of renewable energy for electricity production it would be possible to reduce the fossil fuel TPES of EG&W.

These synergies between countries and sectors are very important when designing an energy strategy. Furthermore, it can be used to enhance international cooperation within countries, which will increase the effectiveness of any energy strategy. Recapping, according to the ranking of countries and regions, South Africa has been targeted as the main energy intensive country. Focusing the analysis in that country, the Transport sector (S19) and the Electricity, Gas and Water sector (S13), have been targeted as a priority for energy interventions. Looking to the energy flows, showed in the South African Energy Map, it is possible to see that, in this case, it is possible to act in the direct energy requirements, or in the indirect (i.e. to act on the energy resources used by both sectors, or on the energy conversion process related to them, or on the productive processes, or on the final demand by individuals).

In addition, regarding the ranking of countries, and the analysis of energy dependency, focus have been also put on Botswana and Namibia, which forms the sub-region of Southern Africa. Analyzing the energy metabolism of Southern Africa, by means of the Regional Energy Map, a great second-degree dependency has been revealed and confirmed, with respect of South Africa. Specifically, the main consuming sectors in Southern Africa in terms of CBA, depend strongly on the two targeted sectors of South Africa.

Target Country	South Africa	**Target Sectors**	Transport (S19) Electricity, Gas and Water (S13)
Synergies/ Relationships/ Dependencies	Southern Africa	**Sectors**	Construction (S14) Public Admin (S22)

Now, it is possible to identify action areas, and stakeholders in the benchmarking process, and select quotations and recommendations in order to build a preliminary energy strategy.

Stakeholders in South Africa:

- Public sector (Local, Regional, National and International) of South Africa.
- Private sector (SMSE and Large Enterprises) of South Africa.
- Civil Society (Non-Profit and Profit organization).
- Academia.
- Research (Public and Private).

Action Areas in South Africa

- Energy resources.
- Energy conversion.
- Transmission and distribution.
- End-Use devices and Building environment
- Policies
- Capacity building.
- Behavioral change.
- Entrepreneurial attitude.
- Integration and coordination of policies

However, as has been demonstrated, Southern Africa most consuming sectors in terms of embodied energy, are quite linked to the target sectors in South Africa. This means that an important energy benefit will go to Southern Africa, from a CBA point of view. In other words, Southern Africa has an incentive to collaborate with South Africa in an improvement of efficiency, or reduce fossil fuels consumption in S19 and S13 in South Africa. Thus, it is also possible to identify key stakeholders and action areas, regarding the Southern African context, in order to help or enhance improvements in South Africa sectors S13 and S19.

Stakeholders in Southern Africa:

- Public sector (National, International).
- Private sector (Large Enterprises).
- Academia.
- Research (Private and Public).

Action areas in Southern Africa:

- Energy resources.
- End-Use devices and building environment.
- Policies.
- Capacity building.
- Integration and coordination of policies.

In that way, keeping in mind the targets, and selecting the quotations and the recommendations from the benchmarking matrix in a rational way, a first approach to an energy strategy towards energy efficiency improvements or energy savings in **Transport** (S19) and **Electricity, Gas and Water** (S13) sectors in **South Africa.**

Energy Strategy for Transport and Electricity, Gas & Water in South Africa.

South Africa

Then, the selected quotations and recommendations from the benchmarking matrix mentioned above, are listed, highlighting the main responsible stakeholder, and the action area in which they should be applied.

- **South Africa Public sector: Local**
    - End-Use devices and Building environment:

1. Smart grids can be paired with smart appliances or even a whole smart home or building, which respond to varying electricity supply and prices.
2. Retrofit municipal and public buildings, street lighting and urban water pumping systems by incorporating efficiency criteria into procurement practices, including energy savings performance contracting.
3. Policies aimed at cutting energy use in the buildings sector through the adoption of more efficient appliances, lighting, heating systems and buildings insulation (e.g. the Eco-design, Energy Labelling and Energy Performance of Buildings Directives).
4. Scheme to increase energy efficiency in central heating systems in buildings, with a goal to save XX million m^3/day of natural gas.
5. Replace XX million inefficient light bulbs used for street lighting in XX cities by 20XX.
6. Review and identify policies at the national and local level that help to accelerate the replacement cycle for “worst in class” facilities and buildings with respect of their relative energy performance.

7. Waste heat recovery: In 2015, the government announced that by 2020, it will replace 50 Mt of coal for district heating with low-grade waste heat energy. The government will provide financing support to local governments to identify and harness waste heat energy sources for new buildings.
    - Policies.
1. Many commercial and industrial businesses face a lack of access to financing for energy efficiency projects. Low-cost loans and other financing mechanisms can provide increased opportunities for energy savings projects to be implemented.
2. Plan transit-oriented developments so residents can either walk or easily take public transit.
3. Support sustainable transport, with multi-modal transport infrastructure, mass rapid transit systems and railway transport
    - Behavioral changes.
1. To cut fossil fuel use for transportation needs, cities need to develop attractive public transport systems and must increase the share of non-motorized transport in developing specific infrastructure (such as cycling lanes and walkways), and optimize delivery of goods, (for instance by promoting the use of rail for cargo transport).
2. Introduced subsidies for hybrid/electric bicycles, buses and cars. Prepared the second cycle (2016-2019) of the Performance Achieve and Trade scheme, which will include refineries, distribution companies and railways.

- **South Africa Public sector: Regional**
    - Energy resources.
1. Central station power generation, mini-grids, and distributed renewable generation can help reduce energy intensity, realize energy savings, lower the carbon footprint, create jobs and markets for energy efficiency related products and services.
2. Announced targets for coal-fired power plants based on coal consumption per unit of power supplied in 2020, and action plans to phase out inefficient technologies and upgrade existing ones.
    - Energy conversion.
1. Support forecasting of renewable power sources to facilitate integration into the grid and plan for environmentally and economically efficient back-up capacity.
2. Monitoring efficiency levels in new energy generation capacities.
    - Transmission and distribution
1. Clean energy mini-/micro-grid solutions using both renewables and conventional sources for rural applications, health care settings, solar-powered street lighting and energy for small businesses and agricultural purposes.
    - End-Use devices and Building environment
1. Wind-driven water pumps are reliable systems that require little attention in their operation and have the potential to meet 100 percent of the water requirements for domestic use and production use by a large share of the population in temperate, arid, and cold areas.
2. Evaluate and promote opportunities for faster development and introduction of more stringent domestic vehicle fuel efficiency requirements and air pollution emissions standards for new vehicles, as well as related national fuel quality standards and green freight programs.

- **South Africa Public sector: National**
    - Energy resources.
1. Exploit and develop the hydropower potential of river basins of Africa.

2. Energy intensity improvements are the primary factor softening the coal demand in the power sector. The combined effect of improving energy intensity and increased generation from renewables and nuclear worked to reduce coal generation.

   - Energy conversion.

1. Establish efficiency targets for existing and new generation assets and develop technologies and approaches to reach them.
2. Implement or increase fuel standards for internal combustion engine vehicles.
3. By developing energy sources such as large hydro power, wind power, geothermal power, and liquid biofuels, developing countries can reduce their dependence on oil and natural gas, creating energy portfolios that are less vulnerable to price fluctuations.
4. Support mechanisms for renewable energy (or more efficient energy) technologies in power sector: Price premiums, Cash grants, Green certificates, Net metering, Feed-in tariffs, Power purchase agreements, Auction tenders, Required share, Tax credits or exemptions, Preferential financing rates, Accelerated depreciation.
5. Promoting high-efficiency boilers and eliminating low-efficiency coal boilers: Seven Chinese ministries and departments have prepared a joint plan to boost the share of high-efficiency large coal boilers from 5% to 40%, while also eliminating low-efficiency coal boilers. By the end of 2015, the Beijing, Tianjin and Hebei urban areas had eliminated all inefficient coal-fired boilers.

   - Transmission and distribution.

1. Energy distributors or retail energy sales companies have to achieve X% energy savings per year through the implementation of energy efficiency measures

   - End-Use devices and Building environment.

1. Scheme to replace XXXXX old inefficient heavy-duty diesel vehicles.
2. An engine standard, coupled with a regulation promoting more fuel-efficient tires, will maximize fuel and emissions benefits as soon as possible

   - Policies.

1. Craft robust renewables policies and power-price purchase agreements on which renewables developers, utilities and business can rely.
2. Rationalize and phase out inefficient fossil fuel subsidies.
3. Establishment and strengthening of private sector regional associations such as the Petroleum and Gas Association, and regional associations of regulators.
4. Increased tax incentives for energy efficiency savings.
5. Establish legislation and labeling-specific regulation to empower agencies to implement and enforce the program. Introduce complementary fuel efficiency policies such as efficiency standards and fiscal incentives linked to fuel efficiency in addition to the VFEL (Vehicle fuel efficiency label) program to improve policy effectiveness.
6. Make the VFEL program mandatory to maximize program effectiveness. Design a program that covers all new and used light-duty vehicles with all fuel types. Conduct comprehensive market research and survey consumer expectations of fuel efficiency regularly. Collect in-use fuel consumption performance data and, via a correction factor or revised test cycle, ensure the label values align with vehicle real-world performance.

   - Behavioral change.

1. The introduction of the system of labels and fiches concerning energy consumption or conservation is accompanied by educational and promotional information campaigns aimed at promoting energy efficiency and more responsible use of energy by end-users.

2. Establish a user-friendly VFEL website providing additional services beyond the fixed information on the label. Require fuel efficiency information in promotional materials through other major media, especially online sources. Build two-way communication channels to collect and respond to questions and comments from consumers.
    - Integration and coordination of policies.
1. Strengthen coordination among private, international and national stakeholders at global, regional and national levels.
2. Many countries are collecting data on aspects of energy code implementation, and the collaborative sharing and comparing of data would be useful, for example in determining code compliance or effective performance measurement (as described in the section on code compliance checking systems). Having database structures that are standardized or at least similar would facilitate these analyses.

- **South Africa Public sector: International**
    - Energy resources.
1. Coordinated development of hydropower.
    - End-Use devices and Building environment.
1. Establishment of a labeling International program is a typical forerunner of fuel economy standards. Labeling programs are in place in many major markets. Benefits of labeling include: (1) disclosing more information on vehicle fuel economy and helping consumers to recognize clean vehicles; (2) encouraging auto manufacturers to expand production and marketing of clean vehicles; (3) reducing petroleum consumption and CO2 emissions, thereby enhancing national energy security.
    - Policies.
1. Economies without Labelling Legislation Should:

-Identify and empower government agencies that should be responsible for the development and implementation of a VFEL program.

- Improve regulatory agencies' technical and management capacity to prepare for the development and introduction of a VFEL program.

- Allocate a budget for VFEL program development and implementation. Consult stakeholders (e.g., vehicle manufacturers and consumers) and the general public on the introduction of a VFEL program.

- Establish the legislation, if necessary, regulation, and technical specification detailing requirements of a VFEL program.

- Collect vehicle fuel efficiency related information from vehicle dealers' and manufacturers' associations, and encourage manufacturers to voluntarily disclose fuel economy information.

- Conduct relevant market research to better understand their existing fleet.

- Develop and design a VFEL program and label requirement based on suggested best practices.

- Establish a compliance and enforcement mechanism to monitor, evaluate and improve the program.

- Introduce other fuel efficiency policies, such as fuel economy/CO2 emissions standards, vehicle tax or incentive based on fuel economy, etc., to maximize the collective impact of the all fuel efficiency policies.

    - Behavioral change.
1. Encourage all governments to periodically review their approach to fuel economy and ensure that there are implementing cost-effective solutions which maximize the economic and environmental benefits.

2. Labelling: Present vehicle fuel efficiency and/or CO2 emissions in both absolute value and comparable grade rating. Link label to fiscal expense or benefit where possible by presenting running cost or fiscal information. Make information for alternative fuel vehicles comparable to conventional vehicles, through metrics such as gasoline equivalent fuel efficiency, CO2 emission, running cost, and financial information. Provide additional information for alternative fuel vehicles to allow comparison across all relevant vehicles.

  - Integration and coordination of policies.

1. Actively support international cooperation among governments on a bilateral or multilateral basis, including regional cooperation and market integration.

- **South Africa Private sector: SMSE's**
  - Entrepreneurial attitude.

1. Decentralized RETs such as solar photovoltaics (PV), biogas digesters, biomass gasifiers, biofuels, small wind-electric turbines, and micro-hydro systems are often a more affordable way to extend energy services.
2. RETs may use locally available resources to provide micro-enterprises thermal, mechanical, or electrical energy while minimizing the adverse environmental impacts.

- **South Africa Private sector: Large Enterprises**
  - Energy resources.

1. Capture and redeploy wasted energy and heat, including natural gas that is now burned off through 'flaring'.

  - Energy conversion.

1. Address the energy-water nexus through renewables-based desalination and energy-efficient irrigation pumps.

  - Transmission and distribution.

1. Improve smart grid technology solutions, grid-scale storage, and interactions between renewables and fossil fuels to reduce grid losses and support generation from intermittent renewable resources and new load patterns from consumers.

  - Policies.

1. Recognize consumer needs and provide distributed electricity solutions that support productive use and economic development through local business creation.

  - Behavioral change.

1. Inclusion of the costs of externalities (such as negative health outcomes and damages associated with climate change) would be appropriate from a social perspective and would shift the comparisons in favor of low-carbon technologies and away from conventional fossil-fueled power plants (Competitiveness Analysis).

  - Integration and coordination of policies.

1. Develop a coordination mechanism for sustainable energy finance with the ability to match financing needs emerging from national energy plans with existing sources of philanthropic, public, and private funds.
2. Green Freight programs are win-win for both the public and private sectors. Typical Green Freight programs are established through some sort of public-private partnership that can improve efficiency and reduce emissions by a number of different mechanisms that appeal to both the public sector and the private sector. Examples include accelerated renewal or modernization of fleets, guidance on implementation

technologies or strategies that reduce fuel consumption and decrease emissions, and enabling the flow of funding through financing programs.

- **South Africa Civil society: Non-profit organizations**
    - Behavioral change.

1. Educate drivers on fuel-efficient driving (eco-driving) and encourage on-board use of eco-mode functions.

- **South Africa Civil society: Profit organizations**
    - Behavioral change.

1. Information campaign targeted at energy-efficient vehicles.

    - Entrepreneurial attitude.

1. Renewable energy can also contribute to improved health by providing energy to refrigerate medicine, sterilize medical equipment, and incinerate medical waste. And it can provide power for supplying the fresh water and sewer services needed to reduce the burden of infectious disease.

- **South Africa Academia**
    - Energy resources.

1. Improve and disseminate resource assessment methodologies and develop technical assistance capacity to help countries map resource availability and develop expansion plans.

    - Capacity building.

1. Implement technology-specific peer-to-peer learning and mentoring programs, fostering exchanges of local innovations and market development techniques.

- **South Africa Public Research**
    - Energy resources.

1. India is in the process of developing fuel efficiency standards for new heavy-duty vehicles (HDVs), and one of the most critical inputs to regulatory development is a technology potential analysis to determine the efficiency levels that the fleet can reasonably achieve over the duration of the regulation.

- **South Africa private Research**
    - Transmission and distribution.

1. Improve capabilities and methodologies to make informed assessments of optimal grid infrastructure coverage, expansion, and reliability to serve local circumstances.

    - End-Use devices and Building environment.

1. Engine modernization in the heavy-duty sector requires the continued largescale transition from mechanically to electronically controlled engines.

    - Policies.

1. Form partnerships that leverage academic research to innovate and help diffuse and scale up proven technology.

Southern Africa

- **Southern Africa Public sector: National**
    - Energy resources.

1. Exploit and develop the hydropower potential of river basins of Africa.

- Integration and coordination of policies.

1. Promote regional coordination and share information on test procedures, methods to align results from different test cycles, test data (e.g., to create national fuel consumption databases), labeling metrics, and compliance regimes, in order to reduce barriers to trade in fuel efficient vehicles.
2. Strengthen coordination among private, international and national stakeholders at global, regional and national levels.
3. Many countries are collecting data on aspects of energy code implementation, and the collaborative sharing and comparing of data would be useful, for example in determining code compliance or effective performance measurement (as described in the section on code compliance checking systems). Having database structures that are standardized or at least similar would facilitate these analyses.

- **Southern Africa Public sector: International**
  - Energy resources.

1. Coordinated development of hydropower.

  - End-Use devices and Building environment.

1. Establishment of a labeling International program is a typical forerunner of fuel economy standards. Labeling programs are in place in many major markets. Benefits of labeling include: (1) disclosing more information on vehicle fuel economy and helping consumers to recognize clean vehicles; (2) encouraging auto manufacturers to expand production and marketing of clean vehicles; (3) reducing petroleum consumption and CO_2 emissions, thereby enhancing national energy security.

  - Policies.

1. Improve and disseminate resource assessment methodologies and develop technical assistance capacity to help countries map resource availability, grid expansion plans, and the need for decentralized electricity solutions.

  - Integration and coordination of policies.

1. Actively support international cooperation among governments on a bilateral or multilateral basis, including regional cooperation and market integration.

- **Southern Africa Private sector: Large Enterprises**
  - Integration and coordination of policies.

1. Develop a coordination mechanism for sustainable energy finance with the ability to match financing needs emerging from national energy plans with existing sources of philanthropic, public, and private funds.
2. Green Freight programs are win-win for both the public and private sectors. Typical Green Freight programs are established through some sort of public-private partnership that can improve efficiency and reduce emissions by a number of different mechanisms that appeal to both the public sector and the private sector. Examples include accelerated renewal or modernization of fleets, guidance on implementation technologies or strategies that reduce fuel consumption and decrease emissions, and enabling the flow of funding through financing programs.

- **Southern Africa Academia**
  - Energy resources.

1. Improve and disseminate resource assessment methodologies and develop technical assistance capacity to help countries map resource availability and develop expansion plans.

  - Capacity building

1. Implement technology-specific peer-to-peer learning and mentoring programs, fostering exchanges of local innovations and market development techniques.

- **Southern Africa Public Research**
  - Integration and coordination of policies.

1. Publishing the conclusions of their research, with identified policy options and case studies to share experiences and best practices among partners.

- **Southern Africa Private Research**
  - Policies.

1. Form partnerships that leverage academic research to innovate and help diffuse and scale up proven technology.

So, by combining the results of the benchmarking process and the results of the joint PBA-CBA energy analysis, a first approach to an energy strategy involving several countries at different levels is done. This is only the first step of an iterative procedure. The next step would be to target new countries and sectors, repeating the whole process, and fulfilling and complementing the energy strategy and/or develop different strategies depending on the region or countries.

5 Conclusions, achievements and future works

In this chapter, conclusions and main achievements of this work are presented. As can be seen in the study case, both energy accounting methods, PBA and CBA, are not necessarily antagonist. It could be treated as complementary. This is a remarkable point due to the lack in literature about combined energy accountings, and the disadvantages consequence of the single application of conventional PBA (used by most organizations and databases for energy accounting). It is also remarkable from the side of keeping aware policy-makers in order to have the proper information for policy design when looking for energy improvements.

Combined use of PBA and CBA. From a technic, or theoretical point of view, the main achievements of this work rely on the methodology capable to represent a whole energy metabolism, in several levels, departing from primary energy production and arriving to final demand of goods and services by individuals. This approach allows researchers to avoid the main drawbacks of the two accounting methods, but keep their many advantages and the useful information provided by both.

The Energy Maps. The methodology admits also a change of scope, being possible to focus in the global economy, in sub-region formed by several countries, in a single national economy, or even a single economic sector belonging to one country. This allows researchers or policy-makers advisers to decrypt the energy relations between countries and economic sectors, and find the optimal way of introducing energy interventions. In each one of the scopes, different useful information is exposed, and depending on the level of the strategy to be designed, it would be better to pay more attention to one kind of map or another.

Identification and classification of different energy dependency degrees. Based on these Energy Maps, it is also possible to state a new classification and definition of three different degrees of energy dependency. Namely, *first-degree energy dependency*, when the dependency relies directly in energy resources (i.e. natural gas, oil, coal, electricity, etc.), it is the conventional energy dependency, clearly highlighted through conventional PBA. The *second-degree energy dependency*, referred to the dependency acquired, in terms of embodied energy, through intermediate transactions between economic sectors in order to get the necessary inputs to produce its goods and services. And the *third-degree energy dependency*, acquired when imports and exports of goods and services used for satisfying final demand of individuals. This classification of energy dependency is closely related to the three ways of energy improvement described in the beginning: *Resource use*, which states for a shift in use of energy resources from fossil fuels to domestic renewable sources. Since the energy accountings are based on fossil fuels, that will represent an improvement on efficiency, and also a decrease on first-degree energy dependency. *Energy efficiency*, understood as an improvement in technology that allows to achieve the same outputs using less energy inputs (directly and indirectly). An energy efficiency improvement, will mean a decrease on second-degree energy dependency. And *Energy savings*, that could be understood as a decrease in energy consumption due to a reduction on final demand by individuals. An enhancement of energy savings, could mean a reduction in third-degree energy dependency.

Furthermore, the previous three levels both of energy dependency and energy improvements, can be related to three levels of trade, namely, the trade of primary resources, the trade of intermediate products between economic sectors, in the same or a different country, in order to achieve the necessary inputs for their production, and the trade of final goods and services between countries, used directly to satisfy final demand of individuals.

Energy Analysis Algorithm. Another very important achievement, is the combination of the different approaches presented in a specific and well-defined method for energy analysis dedicated to policy-makers advisement and the design of energy strategies taking into account a wide range of stakeholders and action areas. The algorithm is capable of provide technical results and link them with specific recommendations, ideas, or policies, extracted from specialized literature clarifying the responsible stakeholder and the related action area. However, one drawback should be highlighted. Despite the fact that the relationships and dependencies between economic sectors and/or countries have been exposed, and it is a valuable help for analyze the energy metabolism of a region, country or productive sector; and for design energy policies or energy strategies by exploiting synergies and mutual benefits; it is impossible, from the statements done in this work, to predict or model the impact or influence of the application of the energy strategies designed, or specific policies or energy interventions. That survey is left for future works and research. It is possible to state, for example, that Construction sector in Southern Africa, will be indirectly benefited by an energy improvement in Transport sector in South Africa, but this benefit cannot be predicted or quantified in a reliable way. An interesting future work or survey departing from the statements made in this thesis would be the development of a theoretical model or paradigm, that allows researchers to mathematically model and forecast the applications and consequences of energy policies or interventions.

By using the so called Structural Decomposition Analysis (SDA) [74] theory, which is usually used to compare, or analyze the changes between two time lapses in economies, it is possible to stablish a preliminary way to forecast the impact of an energy intervention. Modeling somehow the direct improvements introduced by the action, but also its costs and its demand modifications, including it in MRIO tables, and using SDA for analyze the changes between the hypothetical new situation and the previous one, these changes will represent a first order impact forecast for the measure or policy analyzed. However, this statement would require a proper and solid algorithm to mathematically model the possible energy interventions, and despite of that only the first order consequences will be forecasted (since this methodology will be based in a linear model). So, for a proper forecast will be necessary to include non-linear model, analyzing also the changes in price and in demand, using mathematical models of growth and taking into account concepts like the so called Rebound-effect, or the response of consumers to changes in price based on elasticity models.

Something similar happens with the three energy dependency degrees, regarding energy security. By the statements made in this work is possible to identify the three degrees and, with the proper information, show the different dependencies between countries. However, as showed when defining the dependency degrees, there are direct and indirect effects between countries. To be well aware about the energy situation or response to a change in one or more surrounding economies will be necessary to develop non-linear methods to be able to model and understand how affects a change in the energy model of a certain country to others that depend on it in one or more degrees and direct or indirectly.

6 Annex A: Result of Benchmarking process for Africa

Public Sector: Local Vs Energy Resource

- “A typical bio-gas digester of 6–8 cubic meters in size produces 300 cubic meters of biogas a year and, if manufactured domestically, costs $200–250 and pays for itself over time. These units can be supplied by local companies, as digesters are a simple technology with no need for advanced expertise.” [44]

Public Sector: Local Vs Energy Conversion

- “The widespread issue of using inefficient traditional fuel for cooking requires urgent solutions to avoid serious health and environmental implications (i.e. indoor air pollution and deforestation). Renewable energy-based solutions to improve cooking practices (e.g. improved cook stoves or biogas-based technologies, among others) are effective in reducing polluting fumes. In addition, improved cook stoves can save 35%–80% of wood or charcoal compared to traditional three-stone fires.” [83].

Public Sector: Local Vs Transmission & Distribution

- “Self-contained systems that provide uninterrupted power when the grid fails” [84].
- “Enabling access to reliable modern energy services for all urban and peri-urban poor” [44].

Public Sector: Local Vs End Use - Devices & Building Environment

- “Smart grids can be paired with smart appliances or even a whole smart home or building, which respond to varying electricity supply and prices” [85].
- “Retrofit municipal and public buildings, street lighting and urban water pumping systems by incorporating efficiency criteria into procurement practices, including energy savings performance contracting" [86].
- “Solar home systems (SHS) may be used for running lights, televisions, and radios for a few hours every day, usually replacing kerosene or candles” [44].
- “Policies aimed at cutting energy use in the buildings sector through the adoption of more efficient appliances, lighting, heating systems and buildings insulation (e.g. the Eco-design, Energy Labelling and Energy Performance of Buildings Directives)” [7].
- “Scheme to increase energy efficiency in central heating systems in buildings, with a goal to save XX million m^3/day of natural gas” [7].
- “Require pre-demolition building audits to identify opportunities for building retrofits or component re-use” [7].

Public Sector: Local Vs End Use - Devices & Building Environment

- “Replace XX million inefficient light bulbs used for street lighting in XX cities by 20XX” [7].
- “Review and identify policies at the national and local level that help to accelerate the replacement cycle for “worst in class” facilities and buildings with respect of their relative energy performance” [56].
- “Waste heat recovery: In 2015, the government announced that by 2020, it will replace 50 Mt of coal for district heating with low-grade waste heat energy. The government will provide financing support to local governments to identify and harness waste heat energy sources for new buildings” [15].

Public Sector: Local Vs Policies

- “Many commercial and industrial businesses face a lack of access to financing for energy efficiency projects. Low-cost loans and other financing mechanisms can provide increased opportunities for energy savings projects to be implemented” [87].
- “Cities also need to promote urban agriculture, such as rooftop farming (it is estimated that 30% of urban spaces could be covered). Consumption habits need to change, residents should be encouraged to use more local produce and to take on presumption, the production of one’s own food" [85].
- “Plan transit-oriented developments so residents can either walk or easily take public transit” [88].
- “Enact and enforce stricter building codes and higher appliance energy efficiency standards” [88].
- “Support sustainable transport, with multi-modal transport infrastructure, mass rapid transit systems and railway transport” [37].
- “Introduced energy labels for cooking appliances and a requirement to provide automated stand-by functions on network devices. Implemented regulations for residential ventilation units, gas and electric ovens, cooking hobs and range hoods within the framework of the Ecodesign Directive” [7].
- “Introduce a mandatory energy label for public buildings and include LED lamps in the mandatory efficiency labelling scheme” [7].

Public Sector: Local Vs Capacity Building

- “Local trained workforce to undertake new energy efficiency projects. Investing in local workforce training and accreditation is critical” [87].
- “After receiving training, farmers can build the digesters themselves. A new government program in China, started in 2002, subsidizes farmers who build their own units, providing nearly $100 per digester” [44].
- “The infamous “digital divide” increasingly segregates children educated in schools without energy. Energy is necessary to bridge the technology and education gap” [44].

Public Sector: Local Vs Behavioral Change

- "It's critical to share information with these new energy consumers about the benefits of efficiency - living in better insulated houses, working in efficient buildings or factories, and buying efficient appliances and lighting that allows every kilowatt generated to deliver more services" [87].
- "To cut fossil fuel use for transportation needs, cities need to develop attractive public transport systems and must increase the share of non-motorized transport in developing specific infrastructure (such as cycling lanes and walkways), and optimize delivery of goods, (for instance by promoting the use of rail for cargo transport)" [85].
- "Introduced subsidies for hybrid/electric bicycles, buses and cars. Prepared the second cycle (2016-2019) of the Performance Achieve and Trade scheme, which will include refineries, distribution companies and railways" [7].
- "Encourage materials-sensitive construction and management of demolition waste" [7].
- "Rating and disclosure is a market-based approach that is not prescriptive of outcomes but makes building energy performance visible; and there is growing evidence that building owners and occupants act on information provided through rating and disclosure, even where not required to do so" [89].

Public Sector: Local Vs Entrepreneurial Attitude

- "Stimulating income directly by engaging people in using local resources and selling energy services, as well as indirectly through gains in productivity or expanded economic activity resulting from new energy inputs" [44].

Public Sector: Local Vs Integration/Coordination of Policies

- "Energy planning in line with rural and peri-urban demand" [37].
- "At the local level, modern energy services help to reduce drudgery of women's labor, improve health and education, and stimulate micro-enterprises" [44].

Public Sector: Local Vs Finance, Fund & Risk Management

- "Focus on promoting energy efficiency in the buildings and transport sectors, for example by simplifying access to small-scale finance to unlock the efficiency potential in the buildings sector and taking actions to accelerate deployment of the necessary infrastructure to electrify the transport fleet" [7].
- "Appropriate regional incentives and mechanisms that: stimulate improved energy management; support energy efficient investment choices; and improve awareness of the value of energy efficiency investments with key decision-makers" [56].

Public Sector: Regional Vs Energy Resources

- "Central station power generation, mini-grids, and distributed renewable generation can help reduce energy intensity, realize energy savings, lower the carbon footprint, create jobs and markets for energy efficiency related products and services" [87].
- "Build 'heat maps' of critical areas for attention to address problems of energy access and the deployment of energy efficiency and renewable energy" [88].
- "Rational use of surplus biomass waste from agro-industrial units in rural and peri-urban areas" [37].
- "Announced targets for coal-fired power plants based on coal consumption per unit of power supplied in 2020, and action plans to phase out inefficient technologies and upgrade existing ones" [7].

Public Sector: Regional Vs Energy Conversion

- "Support forecasting of renewable power sources to facilitate integration into the grid and plan for environmentally and economically efficient back-up capacity" [86].
- "Monitoring efficiency levels in new energy generation capacities" [90].

Public Sector: Regional Vs Transmission & Distribution

- "Clean energy mini-/micro-grid solutions using both renewables and conventional sources for rural applications, health care settings, solar-powered street lighting and energy for small businesses and agricultural purposes" [88].
- "Intensive peri-urban electrification projects" [37].

Public Sector: Regional Vs End Use - Devices & Building Environment

- “Implement policy frameworks for clean and efficient cook stoves and fuels” [88].
- “75% of schools, clinics and community centers should have access to electricity” [37].
- “Wind-driven water pumps are reliable systems that require little attention in their operation and have the potential to meet 100 percent of the water requirements for domestic use and production use by a large share of the population in temperate, arid, and cold areas” [44].
- “Introduced MEPS (Minimum Energy Performance Standard) for electric water heaters. Revised voluntary labelling requirements for refrigerators, televisions, office equipment and diesel generators” [7].
- “Evaluate and promote opportunities for faster development and introduction of more stringent domestic vehicle fuel efficiency requirements and air pollution emissions standards for new vehicles, as well as related national fuel quality standards and green freight programs” [89].
- “The combination of co-generation,4 switching to gas boilers, recovering industrial waste heat, identifying distributed solutions, and strengthening demand-side measures through building energy management and consumption-based billing has led to China’s northern urban region becoming the world’s largest and fastest-growing user of district heating. China has seen a considerable shift from coal-powered, heat-only boilers to large co-generation” [15].
- “In 2007, the government launched a building retrofit and heat-metering reform programme with the goal of improving the energy efficiency of 150 million m2 of building area. China issued its first mandatory national building energy efficiency (BEE) standard for new residential buildings in cold regions in 1995. This standard (referred to as the 50% BEE standard) required new buildings to achieve a combined 50% improvement in energy efficiency over buildings constructed on standard designs of the early 1980s. Since August 2010, a 65% BEE standard has become mandatory for new construction in China’s cold climate regions” [15].

Public Sector: Regional Vs Policies

- “Governments must not only institute legislation to regulate energy use and consumption, but must also set up incentive measures that promote research, innovation, and, most importantly, the adoption of greener and more efficient technologies. Sound collaboration and mutual understanding between the private sector — which runs most of the world’s energy systems — and overseeing authorities is therefore paramount for short-term commercial interests not to overshadow long-term environmental concerns and sustainable development opportunities” [85].
- “Improving agricultural and land management, where ecosystems and biodiversity are preserved properly” [37].
- “While grid-connected RETs can have a larger impact on national energy portfolios and the macroeconomic health of a country, decentralized off-grid RETs increasingly contribute to community-level energy development” [44].

Public Sector: Regional Vs Policies

- “Action plan to implement technology upgrades in major coal-consuming industries, including coking and coal-based chemicals” [7].
- “Introduced mandatory labels for air conditioners and heat pumps” [7].

Public Sector: Regional Vs Capacity Building

- “Renewable energy for cooking and heating can reduce the time that children, especially girls, spend out of school collecting fuel” [44].

Public Sector: Regional Vs Behavioral Change

- “Establish technology development and customization centers to respond to the technology needs of small, medium and micro enterprises with a view to improving efficiencies and increasing the share of renewables” [88].
- “Introduce a scheme to switch from diesel to efficient electric pumps” [7].

Public Sector: Regional Vs Entrepreneurial Attitude

- “Integrate energy enterprise creation into agriculture and business development activities” [88].

Public Sector: Regional Vs Integration/Coordination of Policies

- “Promote Private Sector Involvement” [44].
- “Village cooperatives in several regions have demonstrated the capacity to develop local manufacturing of RETs, creating a source of employment not only for the manufacturers, but also for installers and distributors, with additional business opportunities for those who stock spare parts and sell raw materials” [44].

- “Promote regional coordination and share information on test procedures, methods to align results from different test cycles, test data (e.g., to create national fuel consumption databases), labeling metrics, and compliance regimes, in order to reduce barriers to trade in fuel efficient vehicles” [91].

Public Sector: Regional Vs Finance, Funding and Risk Management

- “Address residential retrofit needs by properly valuing energy efficiency and incentivizing investment (such as through utility demand-side management programs, the use of energy service companies, and performance contracting mechanisms)” [88].
- “Appropriate regional incentives and mechanisms that: stimulate improved energy management; support energy efficient investment choices; and improve awareness of the value of energy efficiency investments with key decision-makers” [56].
- “Developing national and/ or regional standards and policies that will support energy efficiency investment processes in key market segments consistent with regional and national priorities and conditions” [56].

Public Sector: National Vs Energy Resource

- “Build sufficient local and regional implementation capacity to expand grid to new areas and reinforce it where demanded” [88].
- “Expand national / regional integration of generation and transmission projects” [86].
- “Exploit and develop the hydropower potential of river basins of Africa” [37].

Public Sector: National Vs Energy Resource

- “Doubling of the consumption of modern fuels including increased energy access for productive uses. The use of modern biomass for industrial purposes should be explored” [37].
- “Energy intensity improvements are the primary factor softening the coal demand in the power sector. The combined effect of improving energy intensity and increased generation from renewables and nuclear worked to reduce coal generation” [15].

Public Sector: National Vs Energy Conversion

- “Establish efficiency targets for existing and new generation assets and develop technologies and approaches to reach them” [88].
- “Implement or increase fuel standards for internal combustion engine vehicles” [88].
- “By developing energy sources such as large hydro power, wind power, geothermal power, and liquid biofuels, developing countries can reduce their dependence on oil and natural gas, creating energy portfolios that are less vulnerable to price fluctuations” [44].
- “Support mechanisms for renewable energy (or more efficient energy) technologies in power sector: Price premiums, Cash grants, Green certificates, Net metering, Feed-in tariffs, Power purchase agreements, Auction tenders, Required share, Tax credits or exemptions, Preferential financing rates, Accelerated depreciation” [7].
- “Promoting high-efficiency boilers and eliminating low-efficiency coal boilers: Seven Chinese ministries and departments have prepared a joint plan to boost the share of high-efficiency large coal boilers from 5% to 40%, while also eliminating low-efficiency coal boilers. By the end of 2015, the Beijing, Tianjin and Hebei urban areas had eliminated all inefficient coal-fired boilers” [15].
- “Increasing the efficiency of coal-fired power: In autumn 2014, the central government announced the Coal Power Energy Conservation and Emission Reduction Upgrade and Renovation Action Plan, which will phase out inefficient coal plants. The plan sets an emissions target of 300 grammes of coal-equivalent per kilowatt-hour (gce/kWh) for all new coal-fired power, with the average of all coal power generation reaching 310 gce/kWh by 2020. For generating units larger than 600 MW, the average performance will be lower than 300 gce/kWh. The plan is part of the larger strategy to reduce emissions and pollution from coal-fired power in China” [15].

Public Sector: National Vs Energy Conversion

- “India launched the PAT programme in 2012, setting energy consumption targets for 478 of the most energy-intensive industrial enterprises. The first cycle of the PAT programme (2012-15) aimed to reduce energy consumption on average by 4.1% in eight industry subsectors that made up 36% of total industrial energy consumption (2009-10 levels). The majority of the estimated annual savings were expected to come from power generation, followed by iron and steel and cement. Firms could comply with the targets by achieving their own energy savings or by generating energy savings certificates that could be exchanged with other firms on a trading market. The latest assessment of 427 industrial enterprises under the first cycle shows the original target was surpassed with energy consumption reduced by 5.3%, resulting in annual emissions reductions of 31 million tons of CO_2 ($MtCO_2$)” [15].

Public Sector: National Vs Transmission & Distribution

- “Implement transparent transmission/distribution costing mechanisms that drive energy efficiency, and offer a level playing field for connecting energy sources to the grid” [88].
- “Energy distributors or retail energy sales companies have to achieve X% energy savings per year through the implementation of energy efficiency measures” [90].

Public Sector: National Vs End Use - Devices & Building Environment

- “Access to mechanical power within all communities for productive uses” [37].
- “75% of the poor in urban and peri-urban areas should have access to modern energy services for basic needs” [37].
- “Public sector should purchase energy efficient buildings, products and services” [90].
- “Every year, governments will carry out energy efficient renovations on at least X% of the buildings they own and occupy by floor area” [90].
- “Providing all-weather-vehicle accessible roads and access to motorized transport for all communities” [44].
- “Approval of a bill requiring businesses to satisfy standards for energy saving performance for newly constructed large-scale buildings from 20XX” [7].

Public Sector: National Vs End Use - Devices & Building Environment

- “Scheme to replace XXXXX old inefficient heavy-duty diesel vehicles” [7].
- “Strength MEPS (Minimum Energy Standard Performance) for air conditioners” [7].
- “Implement "Code Compliance Checking Systems" a set of processes to determine whether buildings effectively meet applicable energy code requirements” [92].
- “Measuring Performance against Code Required Design The measurement of actual energy performance is important in order to understand the true impact of building energy codes. Collecting data on the actual consumption of buildings can help support the design and implementation of more targeted building policies, while also closing the policy loop by providing data to support the evaluation of existing measures and develop meaningful updates” [92].
- “Develop and track metrics on the gap between actual building energy performance and code design” [92].
- “Fuel taxes in the EU vary substantially across member states, from 0.36 to 0.75 Euros per liter for petrol and from 0.33 to 0.67 Euros per liter for diesel fuel” [93].

- “Real-world fuel consumption gap: On top of the benefits of LDV CO2 targets, closing the gap between laboratory and real-world fuel consumption to 15% could avoid 25 Mt in 2030” [93].
- “An engine standard, coupled with a regulation promoting more fuel-efficient tires, will maximize fuel and emissions benefits as soon as possible” [94].
- “Japan has updated its Building Energy Conservation Law with the aim of reducing energy consumption in both residential and non-residential buildings. This law is enforced in two parts: labelling and incentives from 1 April 2016, and new performance-based building standards from April 2017. The building incentives will reward energy efficiency performance improvements for new buildings and building retrofits with eased restrictions on building size, allowing developers to construct buildings with more floor space. The incentive programme will also introduce a building energy labelling system that will allow energy-efficient building owners to advertise and include the label in contracts” [15].

Public Sector: National Vs Policies

- “Fuel subsidies on cleaner energy carriers will be needed. New rural electrification targets and government commitment and clear roadmaps to achieve these targets” [95].

Public Sector: National Vs Policies

- “Poor regulatory environments and governance challenges that undermine the economic incentives to conserve electricity or invest in energy efficiency and inhibit a vibrant private-sector energy efficiency market. Instituting cost-reflective tariffs with lifeline tariffs for the poor will help ensure that power utilities have a sustainable business model and that vulnerable populations retain access to electricity” [87].
- “To implement a successful global transition to efficient products through an integrated policy approach, including:

- Minimum energy performance standards (MEPS) that remove the least efficient products from the market and thereby encourage innovation and rapid adoption of higher efficiency products. To achieve the greatest impact mandatory MEPS will be the recommended option;
- Supporting policies and mechanisms, such as: labels, financial and behavioral incentives, non-grant funding tools, climate finance (e.g. NAMAs) and electric utility market transformation programs;
- Environmentally sound management including best practices for manufacturing, materials and spent products, to minimize environmental impacts; and,
- Monitoring, verification and enforcement (MVE) to deter market spoilage by non-compliant products and to ensure the delivery of energy, financial and climate benefits” [86].

- “Craft robust renewables policies and power-price purchase agreements on which renewables developers, utilities and business can rely” [88].

- “Adopt procurement policies and targets that stimulate demand for renewables” [88].
- “Encourage regulatory phasing out of inefficient appliances, such as incandescent lamps” [88].
- “Develop a framework for long-term energy planning, including integrated resource planning, incorporating targets and milestones for renewable energy, energy efficiency, and energy access, and dissemination of existing methodologies and best practices in energy planning” [88].
- “Create more favourable business environments with appropriately refreshed (or new) policies, regulations, and energy plans to incentivize commercial investments and develop markets” [88].
- “Rationalize and phase out inefficient fossil fuel subsidies” [88].
- “Optimizing the domestic fuel market” [37].
- “Establishment and strengthening of private sector regional associations such as the Petroleum and Gas Association, and regional associations of regulators” [37].
- “New policies can have a dramatic impact on the pace of introduction of renewable energy, as several developing countries have demonstrated” [44].
- “Although this process has met strong resistance in some countries, such economic tools are being used successfully in some countries, particularly in Europe through carbon taxes to internalize the cost of greenhouse gas emissions” [44].
- “Increased tax incentives for energy efficiency savings” [7].

Public Sector: National Vs Policies

- “UK and Germany base the annual vehicle tax on a vehicle’s average fuel economy, and in South Africa the tax on new vehicles is adjusted for carbon emissions” [96].
- “Establish legislation and labeling-specific regulation to empower agencies to implement and enforce the program. Introduce complementary fuel efficiency policies such as efficiency standards and fiscal incentives linked to fuel efficiency in addition to the VFEL program to improve policy effectiveness” [91].
- “Make the VFEL program mandatory to maximize program effectiveness. Design a program that covers all new and used light-duty vehicles with all fuel types. Conduct comprehensive market research and survey consumer expectations of fuel efficiency regularly. Collect in-use fuel consumption performance data and, via a correction factor or revised test cycle, ensure the label values align with vehicle real-world performance” [91].

Public Sector: National Vs Capacity Building

- “Sufficient technical capacity must be brought to bear to identify, design, and implement the energy efficiency option” [97].
- “By making light more affordable and reliable, renewable energy technologies also permit schools and businesses to operate after dark” [44].
- “Design and implementation of Solar Powered Classrooms” [44].

Public Sector: National Vs Behavioral Change

- “Advocate for strong government efficiency standards, develop monitoring mechanisms, and educate consumers and business” [86].
- “Invest heavily in public transportation infrastructure to increase its use” [86].
- “Support the work of consumer organizations in changing markets for energy-using products through consumer education and innovative financing schemes” [88].

Public Sector: National Vs Behavioral Change

- “Empowering energy consumers to better manage consumption. This includes easy and free access to data on consumption through individual metering” [90].
- “Extend a scheme that reduces electricity tariffs for industries that have implemented energy efficiency measures” [7].
- “Extend producer responsibility, e.g. through systems that levy fees according to weight, recyclability of a material or actions which complicate waste separation” [7].
- “The introduction of the system of labels and fiches concerning energy consumption or conservation is accompanied by educational and promotional information campaigns aimed at promoting energy efficiency and more responsible use of energy by end-users” [98].
- “Incentives include various inducements to improve energy efficiency, such as penalties for code non-compliance and motivational programmes to encourage energy efficiency investments as a prelude to code requirements or as beyond-code measures. Prior to a code coming into effect, incentives can prepare the way, for example, in the form of loans and subsidies to developers and building owners” [92].
- “Establish a user-friendly VFEL website providing additional services beyond the fixed information on the label. Require fuel efficiency information in promotional materials through other major media, especially online sources. Build two-way communication channels to collect and respond to questions and comments from consumers” [91].

- "In May 2016, Germany launched an ambitious energy efficiency package under the umbrella of the National Action Plan on Energy Efficiency, comprising new promotional programmes and a comprehensive public awareness campaign. The campaign (Deutschland macht's effizient) targets energy consumption in all sectors. Important new promotional programmes include:

- Electricity-saving measures via the competitive tendering Step Up! pilot programme.
- Improving recovery of waste heat and promoting efficient technologies in industry.
- A pilot programme for digital energy services, focused on consumer energy savings.
- Incentives to improve the efficiency of building heating systems including for heat pumps" [15].

Public Sector: National Vs Entrepreneurial Attitude

- "Use public funds for loan guarantees, risk mitigation, and first-loss protection and establish global monoline insurance support to help address political and policy risk for sustainable energy investments" [88].
- "Launch communication strategies highlighting entrepreneurship opportunities, policy support mechanisms, sources for technology and access to finance" [88].
- "Renewable energy development can free up financing from oil production and consumption, there is great potential to contribute to new development initiatives. Biofuels, which can be used for both transportation and electric supply, are particularly suited to replace oil derivatives, reducing imports of fossil fuels" [44].

Public Sector: National Vs Integration/Coordination of Policies

- "Strengthen coordination among private, international and national stakeholders at global, regional and national levels" [88].
- "De-risk investment in emerging markets by developing integrated development structures that support local banks and focus on capacity building and financial support for project developers" [88].
- "Create Supportive Policy and Institutional Frameworks" [44].
- "At the national level, energy services facilitate economic development by underpinning industrial growth and providing access to global markets and trade" [44].

- “A growing number of developing country governments have recognized the essential role that renewable energy technologies can play in meeting basic energy needs and achieving the MDGs. Well-designed policies will allow the cost of the renewable options to fall rapidly in the first several years. It is through the combined efforts of governments and the private sector that strong, sustained markets for renewable energy are most likely to develop” [44].
- “Self-regulation, including voluntary agreements offered as unilateral commitments by industry, can enable quick progress due to rapid and cost-effective implementation, and allows for flexible and appropriate adaptations to technological options and market sensitivities. Openness of partici-pation, added value, representativeness, quantified and staged objectives, involvement of civil society, moni-toring and reporting, cost-effectiveness of administering a self-regulatory initiative and sustainability” [99].

Public Sector: National Vs Integration/Coordination of Policies

- “This Directive establishes a framework for the harmonization of national measures on end-user information, particularly by means of labelling and standard product information, on the consumption of energy and where relevant of other essential resources during use, and supplementary information concerning energy-related products, thereby allowing end-users to choose more efficient products” [98].
- “Countries would benefit from sharing methodologies for calculating cost-optimal code provisions (as in the EU) or cost-effective provisions (as in many countries). These methodologies typically include details on how to assess costs and benefits for different parts of the building stock and how to capture as much of the building stock as possible in a statistically representative, yet simplified way” [92].
- “Many countries are collecting data on aspects of energy code implementation, and the collaborative sharing and comparing of data would be useful, for example in determining code compliance or effective performance measurement (as described in the section on code compliance checking systems). Having database structures that are standardized or at least similar would facilitate these analyses” [92].
- “Simplifying public support programmes, where relevant for energy efficiency, to enable their efficient combination with and mobilization of private finance streams to maximize overall funding flows and delivered benefits” [56].
- “Simplify the administrative mechanisms and jurisdiction for energy efficiency policy” [15].

Public Sector: National Vs Finance, Funding and Risk Management

- “A very small shift in the direction of government support and subsidies, from conventional forms of energy toward RETs that harness sustainable resources, would provide significant and immediate impetus” [44].
- “Provide regulatory support for scalable and sustainable business and financial models” [88].

- “States to promote financing facilities for energy efficiency. In Germany, the publicly-owned bank KfW provides preferential loans for energy efficiency retrofits of existing buildings and the construction of new ones” [14].
- “Including direct payments (e.g. grants), fixed remuneration (e.g. feed-in tariffs or premiums), tax rebates, dedicated auctions, green certificates or facilitated financing conditions” [7].

Public Sector: National Vs Finance, Funding and Risk Management

- “Financial institutions require reliable analytical tools to provide sufficient credit certainty and minimize risk premiums on credit facilities. Governments can generate confidence and provide certainty for private investors through well-informed policies and programs” [100].
- “The provision of clear regulatory and investment signals to encourage the uptake of energy efficiency investments within the development and upgrade cycles of our infrastructure, consistent with national development priorities and strategies” [56].
- “Contribute to and facilitate national and, where appropriate, regional mechanisms that make the data needed for energy efficiency measures and investments easily accessible to market participants involved in the development of these investments considering in-country communication protocols and clear systems of labels and certificates” [56].
- “Reviewing accounting and regulatory treatment for energy efficiency investments, where appropriate, to fairly reflect the net benefits and business risks of these investments” [56].
- “Involving public financial institutions, where appropriate, to help formulate lending policies to prioritize and mobilize private capital toward energy efficiency investments in the respective countries” [56].
- “Energy Efficiency Credit Guidelines to stimulate banks’ financing of energy efficiency, especially in the industry and transport sectors. These new guidelines provide practical information to build the capacity of banks on risk management and product innovation for energy efficiency” [56].

Public Sector: International Vs Energy Resource

- “Increase from 10% to 35% or more, access to reliable and affordable commercial energy supply by Africa's population in 20 years” [37].
- “Coordinated development of hydropower” [37].
- “Biofuel can also be produced locally to replace conventional fuels and traditional biomass used for cooking. In a survey of six developing countries (Ethiopia, Malawi, Mozambique, Senegal, South Africa, and Zimbabwe), using the ethanol-based product “Millennium Gelfuel” was found to be cheaper than cooking with an LPG burner or kerosene in five out of six countries, and was cost competitive with charcoal in Zimbabwe and South Africa” [44].

Public Sector: International Vs Energy Conversion

- "Mandatory, target-based energy savings programme for the largest most energy-intensive enterprises" [15].

Public Sector: International Vs Transmission & Distribution

- "Coordinate grid-connected infrastructure strategies so that different renewable energy project developers do not run into the same barriers" [88].
- "Integrate transmission grids and gas pipelines so as to facilitate cross-border energy flows" [37].

Public Sector: International Vs End Use - Devices & Building Environment

- "Introduce MEPS for various household appliances to reduce stand-by power" [7].
- "Establish specific quantified eco-design requirements for some products or environmental aspects thereof in order to ensure that their environmental impact is minimized" [99].
- "Share experiences of cities, regions, and countries on the efficacy of code compliance checking systems" [92].
- "Exchange information on energy performance measurement methodologies (e.g., for whole-building performance and different end uses) and share lessons learned about the policy implications from measurement studies" [92].
- "Widely available, high-quality building materials and components are essential for facilitating compliance with the code. Therefore, market development strategies that increase the supply of products and assure their quality must be fostered in order to support implementation" [92].
- "To require mandatory CO2 certification of HDVs starting in 20xx. Considering this certification start date, HDV CO2 standards could be introduced" [101].

Public Sector: International Vs End Use - Devices & Building Environment

- “Establishment of a labeling program is a typical forerunner of fuel economy standards. Labeling programs are in place in many major markets. Benefits of labeling include: (1) disclosing more information on vehicle fuel economy and helping consumers to recognize clean vehicles; (2) encouraging auto manufacturers to expand production and marketing of clean vehicles; (3) reducing petroleum consumption and CO2 emissions, thereby enhancing national energy security” [93].
- “An important way of improving the fuel economy of vehicle fleets is to introduce minimum standards, most commonly MEPS (Minimum Energy Performance Standards) or CO2 emission limits” [96].
- “The Chinese government also uses tax instruments to achieve energy efficiency objectives. Vehicle taxes, such as consumption tax and acquisition tax, have been reformed to promote small-engine cars. Additionally, the government has used subsidies to actively promote the adoption of energy-efficient vehicles and electric vehicles” [15].

Public Sector: International Vs Policies

- “Improve and disseminate resource assessment methodologies and develop technical assistance capacity to help countries map resource availability, grid expansion plans, and the need for decentralized electricity solutions” [88].
- “Accelerate the development of a climate bond market to help drive liquidity and accelerate the take up of clean energy investment by institutional investors” [88].
- “Reform and harmonize petroleum regulations and legislation in the continent” [37].
- “Accelerating the reduction of energy poverty and vulnerability, by increasing access of households and small economic operators to reliable and affordable energy supplies” [37].
- “Harmonization of energy sector policies, legislation, rules, regulations and standards to facilitate energy market integration” [37].
- “Agree the 2030 Framework for Climate and Energy Policies, setting an indicative energy savings target of at least 27% by 2030” [7].

Public Sector: International Vs Policies

- “Reduce or completely eliminate the value-added tax on goods produced from recycled materials, in order to promote a circular economy” [7].
- “Economies without Labelling Legislation Should:

  -Identify and empower government agencies that should be responsible for the development and implementation of a VFEL program.

  - Improve regulatory agencies’ technical and management capacity to prepare for the development and introduction of a VFEL program.

  - Allocate a budget for VFEL program development and implementation. Consult stakeholders (e.g., vehicle manufacturers and consumers) and the general public on the introduction of a VFEL program.

  - Establish the legislation, if necessary, regulation, and technical specification detailing requirements of a VFEL program.

  - Collect vehicle fuel efficiency related information from vehicle dealers' and manufacturers' associations, and encourage manufacturers to voluntarily disclose fuel economy information.

  - Conduct relevant market research to better understand their existing fleet.

  - Develop and design a VFEL program and label requirement based on suggested best practices.

  - Establish a compliance and enforcement mechanism to monitor, evaluate and improve the program.

- Introduce other fuel efficiency policies, such as fuel economy/CO_2 emissions standards, vehicle tax or incentive based on fuel economy, etc., to maximize the collective impact of the all fuel efficiency policies” [91].

- “Guidelines for sustainable development: With a goal to promote “ecological civilisation” the government has issued five principles, three of which are particularly relevant to energy efficiency: reorienting urban development patterns to limit sprawl; improving resource use and efficiency; and promoting technical innovation and structural change in the Chinese economy. To achieve the principles, the government has detailed actions such as shutting down inefficient industrial capacity and prohibiting the resale and transfer of inefficient technologies to less-developed regions of China” [15].

Public Sector: International Vs Capacity Building

- “Sharing of approaches to training and communication of energy efficiency aspects of building codes would be beneficial to code compliance and implementation efforts. In the early stages of implementation, effective training is particularly critical to raise awareness and make compliance more mainstream” [92].

Public Sector: International Vs Capacity Building

- "Promote and support capacity building initiatives (e.g., workshops) to encourage region-wide adoption of best practices, particularly for economies with no current (Labelling) program in place" [91].

Public Sector: International Vs Behavioral Change

- "Increasing African countries' collective self-sufficiency and strengthening regional inter-dependence in energy services and products" [37].
- "The provision of accurate, relevant and comparable information on the specific energy consumption of energy-related products should influence the end-user's choice in favor of those products which consume or indirectly result in consuming less energy and other essential resources during use, thus prompting manu-facturers to take steps to reduce the consumption of energy and other essential resources of the products which they manufacture" [98].
- "Encourage all governments to periodically review their approach to fuel economy and ensure that there are implementing cost-effective solutions which maximize the economic and environmental benefits" [96].
- "Labelling: Present vehicle fuel efficiency and/or CO2 emissions in both absolute value and comparable grade rating. Link label to fiscal expense or benefit where possible by presenting running cost or fiscal information. Make information for alternative fuel vehicles comparable to conventional vehicles, through metrics such as gasoline equivalent fuel efficiency, CO2 emission, running cost, and financial information. Provide additional information for alternative fuel vehicles to allow comparison across all relevant vehicles" [91].
- "Establish mechanisms to ensure the credibility of the registered fuel efficiency value and empower agencies for enforcement. Design monitoring and reporting systems to encourage compliance of labeling requirement and specify actions for enforcement" [91].

Public Sector: International Vs Behavioral Change

- "Top Runner programme: China is implementing a Top Runner programme similar to the one in Japan. It aims to achieve long-term energy efficiency improvements by implementing efficiency benchmarks, shortening schedules to achieve the standards and providing other policy incentives. The "top runners" are the highest-efficiency product models in three categories: end-use products, energy-intensive sectors and public institutions. These top runners set the benchmark that others in the category need to achieve over a given period. As of July 2016, 16 top runner standards have been proposed for industrial production, including for ethylene, synthesis ammonia, cement, plate glass and electrolytic aluminum" [15].

Public Sector: International Vs Entrepreneurial Attitude

- "Establishment of energy data banks and planning networks" [37].
- "Potential for RET trade among developing countries presents significant economic opportunities" [44].
- "The World Bank's Community Development Carbon Fund (CDCF) links small-scale projects seeking carbon finance with purchasers of verified emission reductions (ERs)" [44].

Public Sector: International Vs Integration/Coordination of Policies

- "Actively support international cooperation among governments on a bilateral or multilateral basis, including regional cooperation and market integration" [88].

Public Sector: International Vs Integration/Coordination of Policies

- "Develop global and regional technology roadmaps that facilitate international discussion and create specific action points that address opportunities and barriers for renewable energy and energy efficiency applications in end-use sectors" [88].
- "Support for the coordinated development of the hydrocarbon market" [37].
- "Joint ventures between state-owned and private companies towards efficiency targets" [7].
- "The disparities between the laws or administrative measures adopted by the Member States in relation to the eco-design of energy-related products can create barriers to trade and distort competition in the Community and may thus have a direct impact on the establishment and functioning of the internal market. Harmonization of national laws is the only means to prevent such barriers to trade and unfair competition" [99].
- "Flexibility in the method for establishing the level of requirements (MEPS/Eco-design) can make swift improvement of environmental performance easier. should be consulted and cooperate Interested parties actively in this analysis. The setting of mandatory measures requires proper consultation of the parties involved" [99].
- "Share information on incentive programmes for beyond-code performance and very low-energy building (VLEB) policies" [92].
- "Exchange information on innovative ways to incentivize private sector initiatives in code compliance" [92].
- "Harmonization of national standards helps reduce development costs for new vehicles and lessens the regulatory burden. This work will include collaboration and exchange of experiences and best practices on relevant national standards" [100].

- "Leading consultative processes with participating members, financial institutions, and private sector experts to identify the policy frameworks required" [56].
- "Carry out regular program evaluation to ensure policy-makers understand what elements of the program are/are not working properly and why" [91].

Public Sector: International Vs Finance, Funding and Risk Management

- "The investment patterns of governments and international finance institutions, regulatory frameworks oriented to conventional energy sources, externalization of costs and benefits, and governmental purchasing policies that favor conventional sources are among the obstacles to advancing renewables. If these barriers are overcome and renewable energy production is scaled up, the cost of the new energy options will decline significantly" [44].
- "Encourage energy efficiency investments and their positive impacts to be systematically considered alongside supply-side investments relating to our energy systems. This can be achieved through consideration of possible reforms relating to decision-making, planning, pricing and regulation of energy and infrastructure investments" [56].
- "Build greater internal energy efficiency investment awareness within public and private financial institutions, expand their use of tailored approaches to structure and facilitate energy efficiency investments, and develop their capacity through the pro-active sharing of good practice. This can be achieved through support for financial institutions which adopt their own systems based upon voluntary energy efficiency investment commitments. These would aim to appropriately govern their own internal decision-making processes, investments in, and interventions to mobilize greater investment in energy efficiency" [56].

Private Sector: SME's Vs Energy Conversion

- "Savings can be made by integrating efficient heating, cooling, insulation, lighting, and water distribution systems in new or rehabilitated buildings that will increase energy retention. Likewise, on site alternative energy sources such as solar panels on a roof can supplement power from the grid. The use of recycled, reused, or low energy building materials will also contribute to a better energy balance" [85].

Private Sector: SME's Vs Transmission & Distribution

- "Develop and implement small-scale renewable energy and smart grid solutions for areas where conditions do not allow for large-scale interconnected grids" [88].

Private Sector: SME's Vs End Use - Devices & Building Environment

- "Buildings themselves have huge energy saving potential if they embrace green or low-energy building concepts and passive design principles" [85].
- "Solar home system development and deployment (including consumer financing)" [88].
- "Share and apply best practices in operations to improve energy productivity and incorporate renewables" [88].
- "Build Projects Around Local Needs and Capacities" [44].
- "Integration of passive solar elements into the design of schools, health care centers, and other infrastructure can also reduce the demand for heating fuels, while improving indoor air quality" [44].
- "Market-driven approach to facilitate energy savings in commercial buildings by aligning the interests of owners and tenants" [7].
- "Many countries have software and tools to support building energy code compliance. Software and tools are used to assist developers, builders, and designers in demonstrating code compliance and to create compliance reports for code officials. They, therefore, help mainstream code implementation by simplifying and clarifying compliance with building energy codes. Having code compliance checking software integrated with design software so that compliance can be evaluated early in the design stage" [92].

Private Sector: SME's Vs Policies

- "Grants or microfinance that could improve households' access to cheap credit, to cover the capital costs associated with a switch to cleaner fuels, and allow purchase of new end-use equipment, such as stoves" [95].
- "Undertake match-making between small enterprises and international companies in niche markets, through product purchases, training, supply chain development and supplier credit" [88].

Private Sector: SME's Vs Capacity Building

- "In respect of training and information on eco-design for SMEs, it may be appropriate to consider accompanying activities (MPES/Eco-design)" [99].

Private Sector: SME's Vs Behavioral Change

- "National incentives for SMEs to undergo energy audits" [90].
- "In order to maximise the environmental benefits from improved design, it may be necessary to inform consumers about the environmental characteristics and performance of energy-related products and to advise them on how to use products in a manner which is environmentally friendly" [99].

Private Sector: SME's Vs Entrepreneurial Attitude

- "Decentralized RETs such as solar photovoltaics (PV), biogas digesters, biomass gasifiers, biofuels, small wind-electric turbines, and micro-hydro systems are often a more affordable way to extend energy services" [44].
- "RETs can boost incomes by preventing loss of a significant fraction of the harvest between gathering and commercialization" [44].
- "RETs may use locally available resources to provide micro-enterprises thermal, mechanical, or electrical energy while minimizing the adverse environmental impacts" [44].
- "The dramatic cost reductions achieved in some renewable energy technologies in recent years, notably in solar PV, have prompted much discussion of their competitiveness with other technologies at both utility-scale and for business" [7].

Private Sector: SME's Vs Integration/Coordination of policies

- "Encourage the integration of ecodesign in small and medium-sized enterprises (SMEs) and very small firms. Such integration could be facilitated by wide availability of, and easy access to, information relating to the sustainability of their products" [99].

Private Sector: SME's Vs Integration/Coordination of policies

- "Small and medium-sized enterprises (SMEs) are the driving force of the German economy. They generate 60% of all jobs and are responsible for 56% of Germany's economic output. The profitability of investment in energy efficiency in German SMEs can yield gains of 20 to 25%, yet numerous SMEs will not undertake such investments as they lack expertise, have difficulties with the access to capital, or overestimate the payback periods of investing in efficiency. In order to counter these barriers, the German Federal Government and 21 business associations launched the Energy Efficiency Networks initiative in late 2014. This initiative aims to progress the sharing of experience between companies on potential savings and technologies on a voluntary basis, as this will enable company experts to plan and execute optimal investments in energy efficiency" [56].

Private Sector: SME's Vs Finance, Funding & Risk Management

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Private Sector: Large Enterprises Vs Energy Resource

- "Capture and redeploy wasted energy and heat, including natural gas that is now burned off through 'flaring'" [88].
- "Scale up the use of sustainable first- and second-generation biofuels without impinging on food and water security" [88].

Private Sector: Large Enterprises Vs Energy Resource

- “Convert to biomass and other renewable sources in industrial processes where possible and sustainable over the longer term, including for co-generation” [88].
- “Improve the reliability as well as lower the cost of energy supply for productive activities in order to enable economic growth of 6% per annum” [37].
- “The Chinese government enacted (from 2006 to 2010) a mandatory energy savings programme, called the Top 1 000 Program, for the 1 000 largest enterprises in nine energy-intensive sectors. In 2005, the enterprises subsequently regulated accounted for 33% of the country’s TFC and 47% of industry TFC. Energy efficiency targets were incorporated into performance evaluations for managers in these companies. In addition, a differentiated electricity pricing system was applied to the cement and aluminum sectors, along with a surcharge for poor energy performance (China State Council, 2013). Finally, an energy efficiency fund was created to support the enterprises concerned” [15].

Private Sector: Large Enterprises Vs Energy Conversion

- “Savings can be made by integrating efficient heating, cooling, insulation, lighting, and water distribution systems in new or rehabilitated buildings that will increase energy retention. Likewise, on site alternative energy sources such as solar panels on a roof can supplement power from the grid. The use of recycled, reused, or low energy building materials will also contribute to a better energy balance” [85].
- “Cities need to ensure that industries pool their resources in order to create synergy effects. This can be achieved by establishing eco-industrial parks, where waste and by-products of one industry serves as the raw material of another, thereby improving material and energy efficiency and decreasing environmental emissions. From an economic perspective, this would also make companies more competitive, as better waste management results in cost savings and a higher environmental and business performance” [85].
- “Develop capacity for installation, operating and maintenance to ensure long-term technical and economic success” [88].
- “Address the energy-water nexus through renewables-based desalination and energy-efficient irrigation pumps” [88].

Private Sector: Large Enterprises Vs Energy Conversion

- “Retrofit commercial offices with advanced lighting, electronics, and heating / cooling equipment, and obtain certification under green building standards” [88].
- “Packaging redesign, re-use of packaging, waste recovery and increasing efficiency of production processes” [7].

Private Sector: Large Enterprises Vs Transmission & Distribution

- "Develop and disseminate existing and new approaches and equipment for expanding the grid to larger areas in a cost-efficient manner, while also strengthening and improving the reliability of existing infrastructure" [88].
- "Improve smart grid technology solutions, grid-scale storage, and interactions between renewables and fossil fuels to reduce grid losses and support generation from intermittent renewable resources and new load patterns from consumers" [88].

Private Sector: Large Enterprises Vs End Use - Devices & Building Environment

- "Buildings themselves have huge energy saving potential if they embrace green or low-energy building concepts and passive design principles" [85].
- "Develop sustainable value chains and robust infrastructure for clean and efficient cook stoves and fuels" [88].
- "Develop and adopt more efficient ship designs with new propulsion and combustion systems or that use renewable fuels" [88].
- "Deploy and scale up energy management systems and tools for reducing energy use" [88].
- "Adopt targets and trajectories for the energy efficiency of products and services, using a life-cycle perspective" [88].

Private Sector: Large Enterprises Vs End Use - Devices & Building Environment

- "In warm climates where the technology is well-established, SHWs (usually augmented by an electrical immersion heater) are fully economical. The technology is characterized by accessible investment cost, complementarity with other water-heating systems, and significant fuel savings" [44].
- "Review minimum structural material requirements to avoid excess material use and building codes to permit the use of reused materials" [7].
- "Promoting efficient lighting in households by providing 150 million LEDs at the cost of incandescent light bulbs to consumers" [7].
- "Action should be taken energy-related products, pollution caused during the since it appears design phase of that the a product's life cycle is determined at that stage, and most of the costs involved are committed then" [99].
- "Reduce the environmental impacts of products across the whole of their life cycle, including in the selection and use of raw materials, in manufacturing, packaging, transport and distribution, installation and maintenance, use and end-of-life. Considering at the design stage a product's environmental impact

throughout its whole life cycle has a high potential to facilitate improved environmental performance in a cost effective way, including in terms of resource and material efficiency" [99].

- "As a general principle and where appropriate, the energy consumption of energy-related products in stand-by or off-mode should be reduced to the minimum necessary for their proper functioning" [99].
- "Gather data on building characteristics and energy use and establish performance benchmarks for building types, including through collaborative studies" [92].

Private Sector: Large Enterprises Vs Policies

- "Recognize consumer needs and provide distributed electricity solutions that support productive use and economic development through local business creation" [88].
- "Provide sustainable energy access to agriculture and SMEs" [88].

Private Sector: Large Enterprises Vs Policies

- "Facilitating sustained high rates of economic growth, by providing operators in the productive sectors with realistically priced electric power and energy supplies" [37].
- "Improve access to modern energy services through integrated food and energy production" [88].
- "Efficiently mesh project preparation, technical assistance for institutional and regulatory development, and debt/equity financing" [88].
- "Clean energy and energy efficiency providing advisory services and financing for supporting initiatives up to 5 GW worth of clean energies or energy efficiencies" [37].
- "Improve material efficiency – delivering the same material service with less overall production of materials. Promoting a higher degree of efficiency in the value chain of production and in the use phase, while making sure that the same service is delivered to the consumer, can take several different forms: reducing the weight of products, while delivering the same service (light-weighting), reducing yield losses in the manufacturing process, finding alternative uses for fabrication scrap without re-melting, re-using and recycling components, creating longer-lasting product components; and using products more intensely or at higher capacity" [7].
- "Support for innovation in manufacturing processes to improve production yields" [7].

Private Sector: Large Enterprises Vs Capacity Building

- "Providing electricity (for such services as lighting, refrigeration, ICT, water pumping and/or purification) for all schools, clinics, hospitals, and community centers" [44]

Private Sector: Large Enterprises Vs Behavioral Change

- "Offer ability to tele-commute to employees to reduce driving demand" [88].

Private Sector: Large Enterprises Vs Behavioral Change

- "Large companies will make audits of their energy consumption to help them identify ways to reduce it" [90].
- "Inclusion of the costs of externalities (such as negative health outcomes and damages associated with climate change) would be appropriate from a social perspective and would shift the comparisons in favour of low-carbon technologies and away from conventional fossil-fueled power plants (Competitiveness Analysis)" [7].
- "Achieving greater efficiency in the use of materials through light-weighting, longer life products, re-use and recycling, is an important complementary strategy to energy efficiency in energy-intensive industries, as the potential for energy savings is about twice as large" [7].
- "Introduce a deposit-return system for beverage containers" [7].
- "Information plays a key role in the operation of market forces and it is therefore necessary to introduce a uniform label for all products of the same type, to provide potential purchasers with supplementary stan-dardized information on those products' costs in terms of energy and the consumption of other essential resources and to take measures to ensure that potential end-users who do not see the product displayed, and thus have no opportunity to see the label, are also supplied with this information" [98].

Private Sector: Large Enterprises Vs Entrepreneurial Attitude

- "Train entrepreneurs" [88].
- "Make effective use of rooftops through the extension of rooftop solar in sunny areas and expanded use of "cool roofs" that employ white paint or reflective tile to limit heating" [88].

Private Sector: Large Enterprises Vs Entrepreneurial Attitude

- "Develop innovative payment approaches that overcome consumer resistance to high up-front costs for energy-efficient and renewable energy technologies (i.e., a lease/sale approach for energy products, and/or pay-as-you-go mobile payments and engaging local financial institutions in providing end-user finance.)" [88].
- "Looking toward RET projects in off-grid areas that focus on productive uses of renewable energy (PURE) as the entry point for market development" [44].
- "Further cost reductions for renewables would provide for them to displace generation from other power plants beyond peaking units, opening up increasing market opportunities" [7].

Private Sector: Large Enterprises Vs Integration/Coordination of Policies

- "Create viable supply chains for upgrading and maintenance" [88].
- "Develop a coordination mechanism for sustainable energy finance with the ability to match financing needs emerging from national energy plans with existing sources of philanthropic, public, and private funds" [88].
- "Exchange information on institutional arrangements for testing materials in different countries, which could help countries improve their systems" [92].
- "Share ways to bring innovative products to market more efficiently" [92].
- "Green Freight programs are win-win for both the public and private sectors. Typical Green Freight programs are established through some sort of public-private partnership that can improve efficiency and reduce emissions by a number of different mechanisms that appeal to both the public sector and the private sector. Examples include accelerated renewal or modernization of fleets, guidance on implementation technologies or strategies that reduce fuel consumption and decrease emissions, and enabling the flow of funding through financing programs" [93].

Private Sector: Large Enterprises Vs Finance, Funding and Risk Management

- “Instead of withdrawing to let private markets develop on their own, development agencies that recognize the potential contribution of RETs are redirecting their efforts to remove barriers and reduce risk in renewable energy markets” [44].

Civil Society: Non-Profit Organizations Vs Finance, Funding and Risk Management

- “Financing must be in place to allow the intertemporal conversion of a flow of future savings into a capitalized investment in energy efficiency improvements” [97].
- “Develop financing schemes to provide credit to households that cannot afford the up-front costs” [88].
- “Expand and harmonize financial de-risking mechanisms and tools, such as loan guarantee mechanisms and partial risk guarantee approaches” [88].
- “Develop innovative consumer tools such as on-bill financing and PACE (property-assured clean energy) bonds” [88].
- “Support the creation of “investing groups” and seed capital funds that help increase the pool of “smart” capital available to invest in sustainable energy” [88].
- “Developing finance mechanisms, where relevant, that can enhance the creditworthiness of the repayment streams to energy efficiency investments, such as including these repayments within existing payment collection mechanisms” [56].

Civil Society: Non-Profit Organizations Vs End Use - Devices & Building Environment

- “Expand the use of alternative fuel vehicles (e.g., natural gas vehicles, flex-fuel vehicles, electric power trains, etc.)” [88].
- “The MoneyMaker is a treadle irrigation pump designed and manufactured in 1996 by ApproTEC, a non-governmental organization in Kenya. Sold for US $53, the MoneyMaker has been proven to increase the average farmer’s productive acreage seven-fold, yielding at least two crop cycles per year instead of one. While the annual income of farms in the country varies from essentially zero to hundreds and even thousands of dollars, ApproTEC has calculated that the pump increases those earnings by an average of $1,400 a year. The pumps generate a collective total of $50 million a year for their owners—more than half a percent of Kenya’s GDP—and have created as many as 25,000 jobs” [44].

Civil Society: Non-Profit Organizations Vs Policies

- “Organize community-based ownership of those activities that individuals cannot afford but that help the whole community” [88].

Civil Society: Non-Profit Organizations Vs Behavioral Change

- “Advocate for and educate consumers about the importance and health, economic, environmental, and gender benefits of clean cooking through women’s (and men's) networks” [88].
- “Train local citizens to sell and service distributed electricity solutions” [88].
- “Educate drivers on fuel-efficient driving (eco-driving) and encourage on-board use of eco-mode functions” [88].
- “Deploy and use advanced technologies to enable energy-saving behavior and raise consumer awareness about simple steps to reduce energy demand from everyday products and through energy efficiency labelling schemes” [88].
- “Programs to raise awareness among households about the benefits of energy audits through appropriate advice services” [14].
- “Raise consumer awareness about ways to reduce material use and the multiple benefits of doing so” [7].

Civil Society: Non-Profit Organizations Vs Integration/Coordination of Policies

- “Provide support for research, development, and demonstration activities in academia, research centers, industry, small and medium enterprises, and local entrepreneurs” [88].
- “Ensure that coordination with energy companies is in place” [37].

Civil Society: Profit Organizations Vs Energy Resource

- “Promotion of photovoltaic (and other RET’s)” [37].

Civil Society: Profit Organizations Vs Policies

- "Promote and support widespread use of new inventions and innovations through competitions to incentivize breakthroughs" [88].
- "Launch an Energy Enterprise Portal combining distance learning techniques with local enterprise development expertise to stimulate preparation of multiple investment-grade energy access business plans" [88].
- "Allocate a portion of investment portfolios to sustainable energy goals, e.g., investing in Sustainable Energy Funds" [88].

Civil Society: Profit Organizations Vs Behavioral Changes

- "Advocate for and educate consumers about the importance and health, economic, environmental, and gender benefits of clean cooking through awareness campaigns" [88].
- "Not only are RETs a hedge against future price increases in conventional fuels, but they improve the balance of trade and create new economic opportunities" [44].
- "Empowering Women (and Men) Through Adoption of Biodiesel Engines" [44].
- "Information campaign targeted at energy-efficient vehicles" [7].

Civil Society: Profit Organizations Vs Entrepreneurial Attitude

- "Renewable energy can also contribute to improved health by providing energy to refrigerate medicine, sterilize medical equipment, and incinerate medical waste. And it can provide power for supplying the fresh water and sewer services needed to reduce the burden of infectious disease" [44].

Civil Society: Profit Organizations Vs Finance, Funding and Risk Management

- "Nurture Micro-Enterprises" [44].
- "For those, lacking access to electricity, the majority of whom are in developing countries, the reliability issue is less pressing in the initial comparison, lowering the relevant size and cost of energy storage. In these applications, renewables are already broadly competitive with the main alternative" [7].
- "Build a pipeline of bankable and replicable energy efficiency projects" [56].

Academia Vs Energy Resource

- "Improve and disseminate resource assessment methodologies and develop technical assistance capacity to help countries map resource availability and develop expansion plans" [88].

Academia Vs End Use - Devices & Building Environment

- "Increasing the availability of reliable and consistent statistics on material flows to increase knowledge about material flows, wastes and lifetimes" [88].
- "Some commonalities in training programmes may include university curricula for efficient building designs, approaches to segmenting training by stakeholder group, and the use of social media and multiple media to expand the reach of training programmes" [92].

Academia Vs Policies

- "Develop monitoring and best-practice sharing facilities and similar mechanisms to spur progress" [88].
- "Offer transformational courses and degree programmes that link innovation in energy and development" [88].

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Academia Vs Capacity Building

- "Implement technology-specific peer-to-peer learning and mentoring programs, fostering exchanges of local innovations and market development techniques" [88].
- "Identification and strengthening centers of excellence for energy research and technology development" [37].
- "Developing skills for using performance-based software, with the recognition that results could be poor for whole building simulation when experts without adequate skills use the simulation software. Unaddressed, these capacity issues limit the effectiveness of whole-building compliance checking" [92].
- "Improve training in the use of performance-based simulation software for more effective whole-building compliance checking" [92].

Academia Vs Behavioral Change

- "Develop the next generation of in-country/institutional leaders" [88].

Academia Vs Finance, Funding and Risk Management

- "Contribute to best practice and capacity building by collecting and analyzing case studies of successful financing initiatives on both the demand side (borrowers) and the supply side (banks and investors). Lessons learned will be disseminated through best practice toolkits, information packs, online tutorials and direct engagement" [100].

Public Research Vs Energy Resource

- "Improve the use of sustainable first- and second-generation biofuels" [88].
- "The development of renewable fuels for cooking should be given more attention, as it is one of the most urgent and widespread energy needs for the poor" [44].

Public Research Vs End Use - Devices & Building Environment

- “Develop industry standards for efficiency, safety, and emission reduction, based on testing and certification” [88].
- “Identify effective practices in conducting physical checks of buildings, including who conducts the checks, how, and when” [92].
- “Develop and share evidence-based studies on the effectiveness of different approaches of Code Compliance checking Systems to enforcement” [92].
- “India is in the process of developing fuel efficiency standards for new heavy-duty vehicles (HDVs), and one of the most critical inputs to regulatory development is a technology potential analysis to determine the efficiency levels that the fleet can reasonably achieve over the duration of the regulation” [94].

Public Research Vs Policies

- “Develop checklists and toolboxes that allow national policy makers to effectively address the different procedural aspects required to introduce large-scale renewables into the grid” [88].

Public Research Vs Behavioral Change

- “Research on how consumer decisions about energy efficiency can be stimulated ("behavioral economics")” [14].
- “Develop evidence-based information on the effectiveness of different incentive schemes” [92].

Public Research Vs Integration/Coordination of Policies

- “Publishing the conclusions of their research, with identified policy options and case studies to share experiences and best practices among partners” [56].

Public Research Vs Finance, Fund & Risk Management

- “Disconnecting the outlook for a technology from specific reliance on political support helps secure a long-term place for that technology in the energy landscape” [7].

Private Research Vs Energy Conversion

- “Share and develop innovative, increasingly cost-effective design and deployment approaches” [88].
- “Innovate on technology solutions that improve overall efficiency (energy productivity) and reduce/eliminate standby/phantom electricity losses” [88].

Private Research Vs Transmission & Distribution

- “Improve capabilities and methodologies to make informed assessments of optimal grid infrastructure coverage, expansion, and reliability to serve local circumstances” [88].

Private Research Vs End Use - Devices & Building Environment

- “Develop more efficient stoves and design products that meet consumer demand” [88].
- “Engine modernization in the heavy-duty sector in India requires the continued largescale transition from mechanically to electronically controlled engines” [102].
- "The technologies for controlling criteria pollutant emissions often have efficiency impacts. For example, selective catalytic reduction (SCR), which is required to achieve the most stringent NOX levels, allows engines to be tuned for increased fuel efficiency. Moreover, the introduction of electronic controls and more sophisticated fuel injection strategies is a boon to efficiency. On the other hand, certain emission control strategies such as exhaust gas circulation (EGR) and diesel particulate filters (DPFs) often have negative fuel use ramifications" [102].

Private Research Vs Policies

- “Form partnerships that leverage academic research to innovate and help diffuse and scale up proven technology” [88].

Private Research Vs Policies

- “Improve separation and collection of dry-recyclables at source” [7].

Individual Citizens Vs Energy Conversion

- “Bangladesh, where 40% of the population lacks access to electricity, had successfully secured, mainly by competitive tender, the installation of solar home systems to 9% of the population by May 2014” [7].

Individual Citizens Vs End Use - Devices & Building Environment

- “Use high-efficiency appliances and lighting systems: for example, a 40-watt solar panel can power a 25-watt incandescent light for almost five hours a day. However, if the latest high-efficiency appliances are used, the same system could power two brighter LED lights for the same five hours, while also powering a color television, a fan, a mobile phone charger, and a radio for more than three hours per day” [87].
- “The major change, however, needs to come from the end-users – residents, businesses, industries –who must control their consumption” [85].
- “Households, offices, and factories can program smart meters to operate certain appliances when power supplies are plentiful. For example, a washing machine can be set up in such a way that it will only start operating when there is enough power in the grid or when the price is under a certain threshold” [85].
- “A number of technical interventions can be employed to reduce indoor air pollution. Stoves can be improved to achieve better combustion and greater efficiency, and flues, hoods, or chimneys can be attached to remove smoke. Changes in kitchen design can increase ventilation and control the distribution of pollution. Most effective, however, is the switch from solid fuels (biomass, coal) to RETs such as biogas, biofuel, and solar” [44].
- “Each “improved” stove represents a 15–30 percent typical efficiency gain in household biomass use. In recent decades, urban areas in developing nations have experienced the highest penetration rates of these stoves” [44].

Individual Citizens Vs End Use - Devices & Building Environment

- "The provision of information on vehicle fuel economy is essential if consumers are to understand the choices available to them" [96].

Individual Citizens Vs Capacity Building

- "By providing sustainable energy for cooking and space heating at low operating costs, improved stoves and alternative fuels can free up this time for education" [44].
- "RETs can also enable a local, reliable, and safe drinking-water supply that increases sanitation levels, reducing ill-health and disease in children and raising attendance in school. Surveys by the Tanzanian Government have found children 12 percent more likely to attend school if they live within 15 minutes of a drinking water source than if they live more than one hour from such a source" [44].

Individual Citizens Vs Behavioral Change

- "Displacement of traditional fuels reduces the health problems from indoor air pollution produced by burning those fuels. Indoor air pollution levels in households that rely on biomass fuel or coal are extremely high; for example, typical 24-hour mean levels for PM-10 (particulate matter) in homes using biomass fuels are around 1000 µg/m3 (micrograms per cubic meter) compared to the current limit of 150 µg/m3, set by the U.S. Environmental Protection Agency" [44].

Individual Citizens Vs Entrepreneurial Attitude

- "Biofuel can be produced domestically to replace conventional fuels and traditional biomass" [44].
- "The dramatic cost reductions achieved in some renewable energy technologies in recent years, notably in solar PV, have prompted much discussion of their competitiveness with other technologies at both utility-scale and for individual households" [7].

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